

# Overview of top quark results (ATLAS+CMS)

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**For ATLAS & CMS Collaborations**



[LHC Top WG](#)

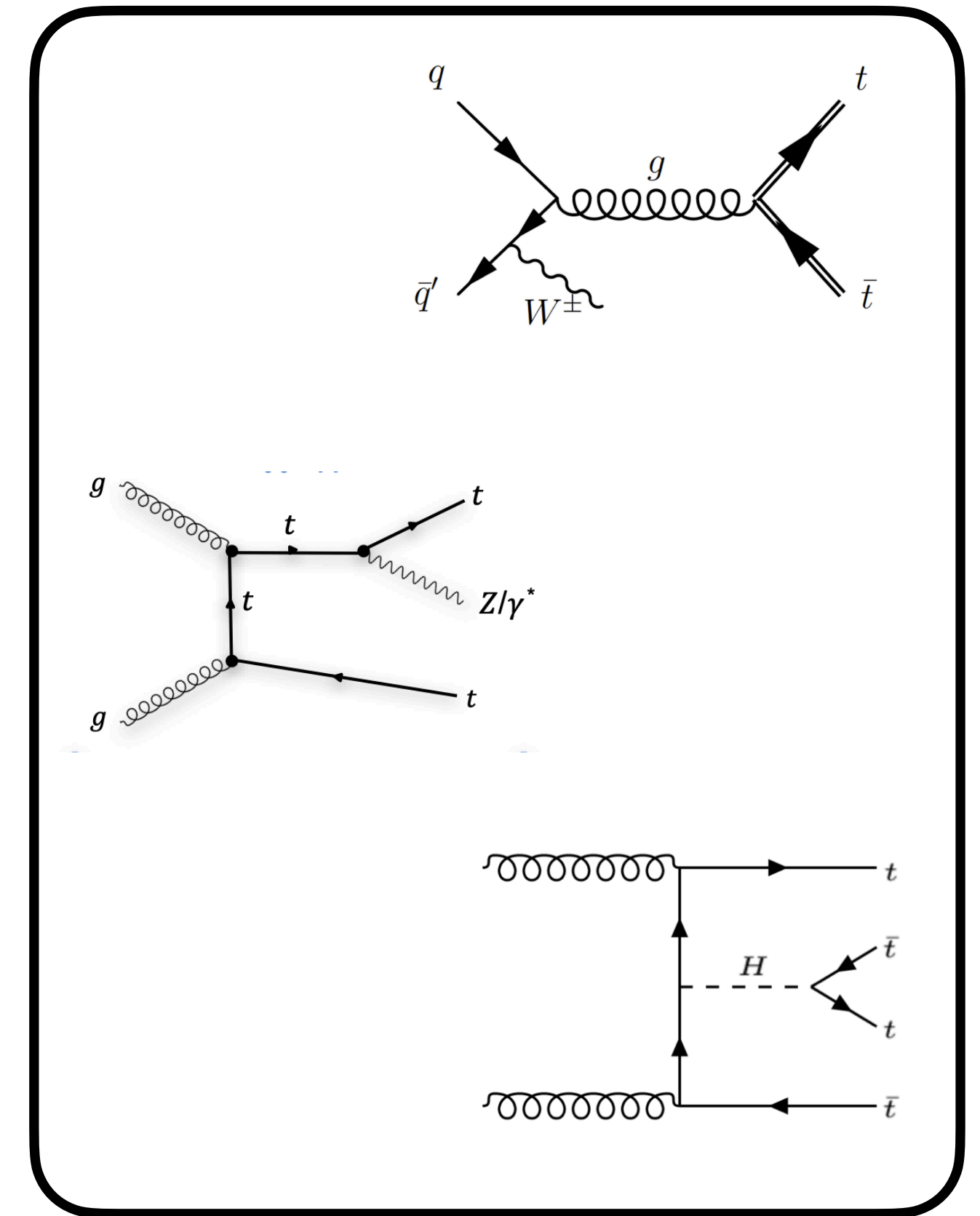
**Brookhaven Forum-2021**

04-November-2021

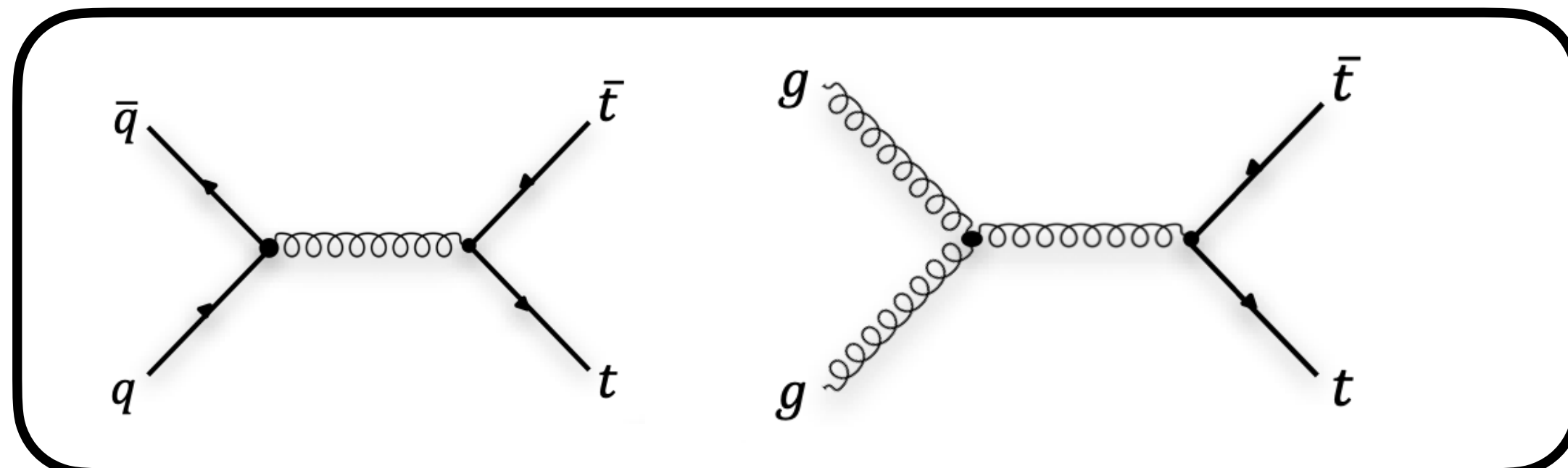
# Introduction

- Top quark is the most massive fundamental particle
  - The Yukawa coupling to Higgs field is  $\sim 1$
  - Do not hadronize: Decays before hadronization time scale.
- Probe for testing Standard Model and BSM Physics
  - Test pQCD predictions at NNLO precision, Constrain PDF's
  - Precision SM measurements (top mass,  $|V_{tb}|$ )
  - Search for anomalous couplings,  $t\bar{t}$  resonances,  $W'$  search

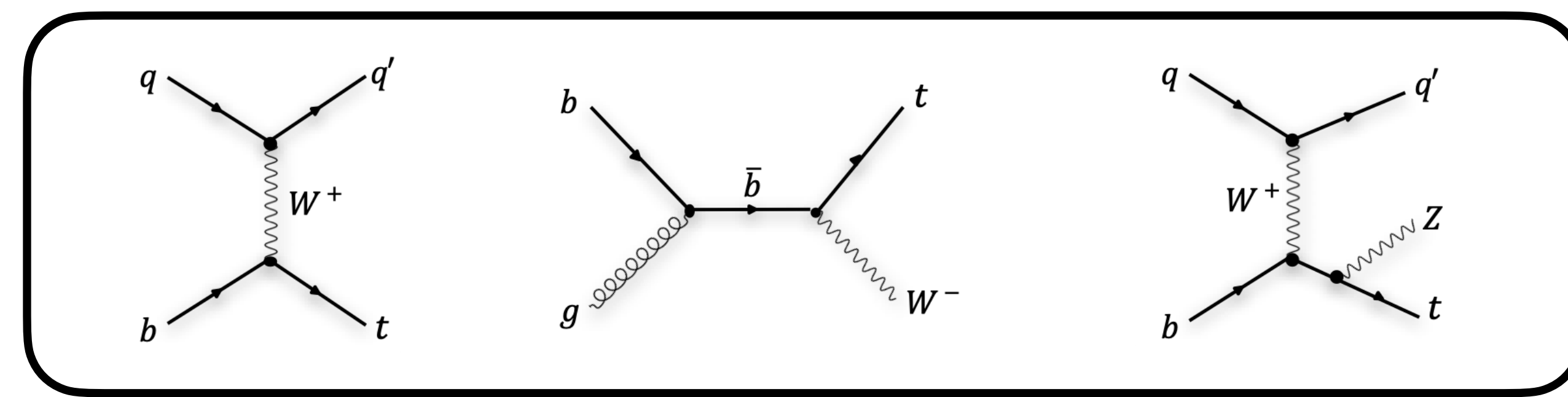
## Rare processes



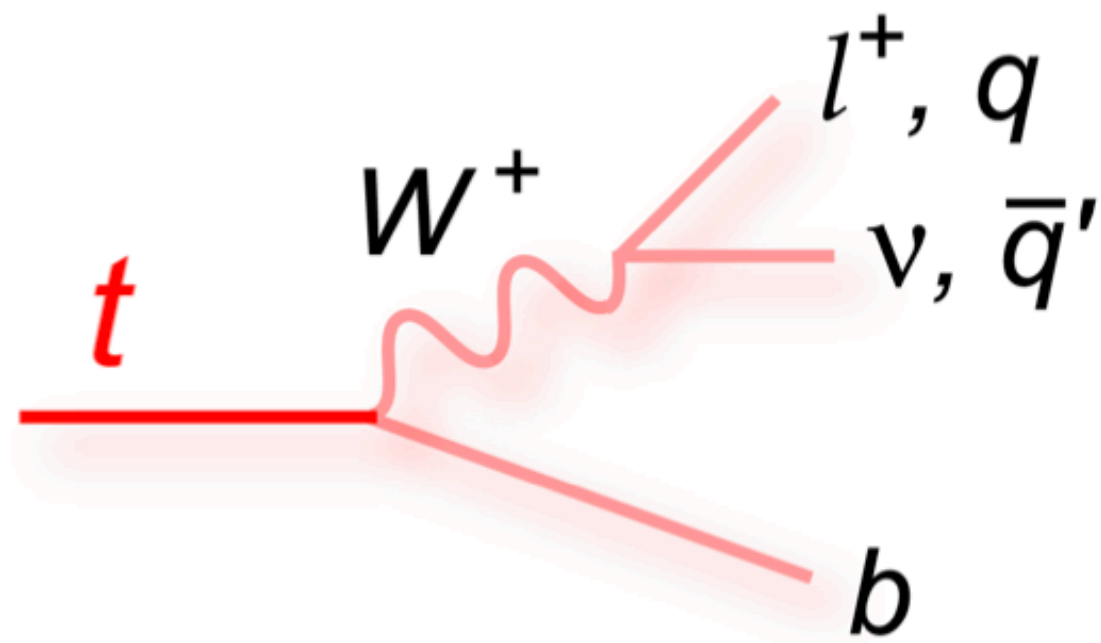
## Pair production



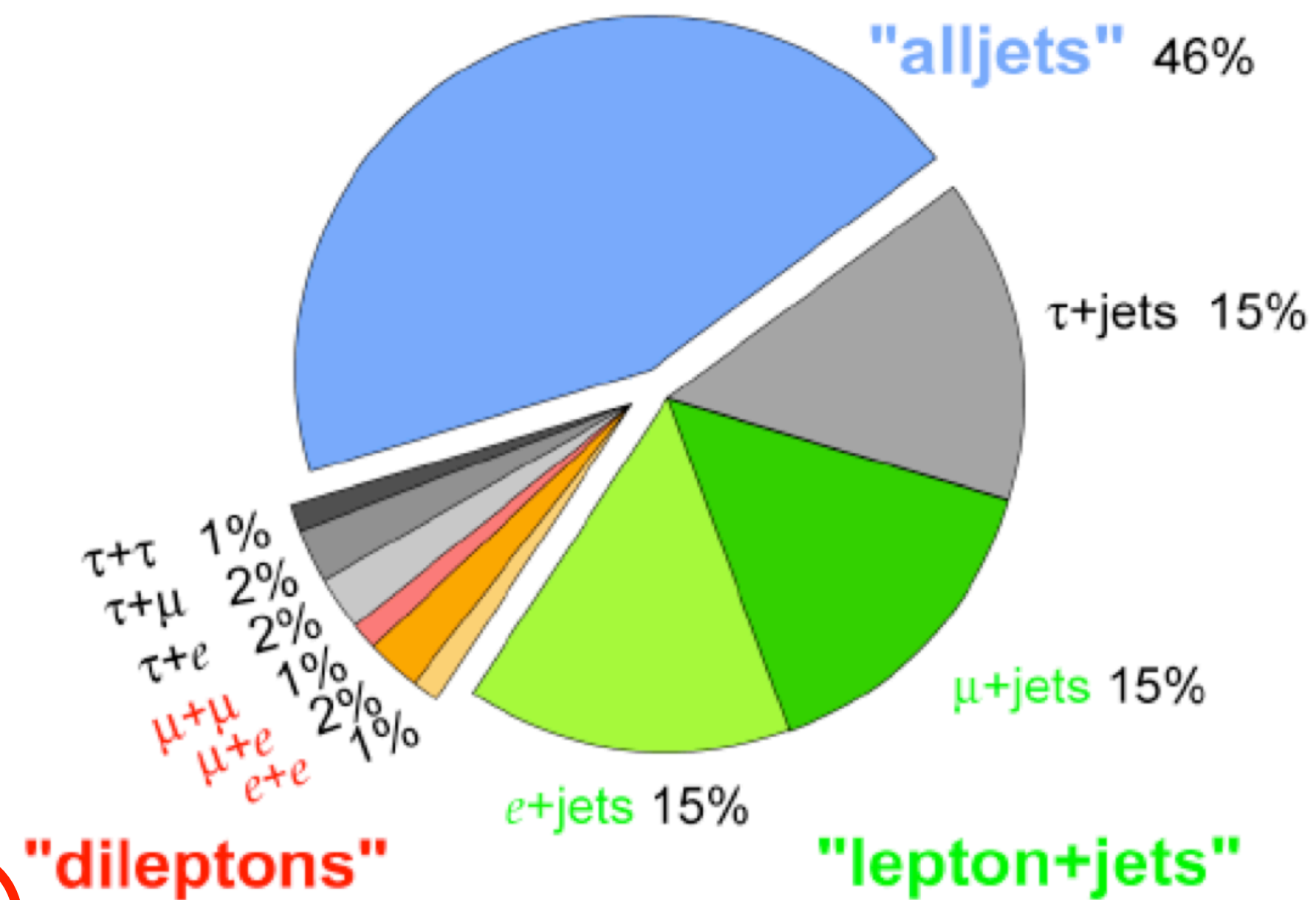
## Single top production



# $t\bar{t}$ pair production



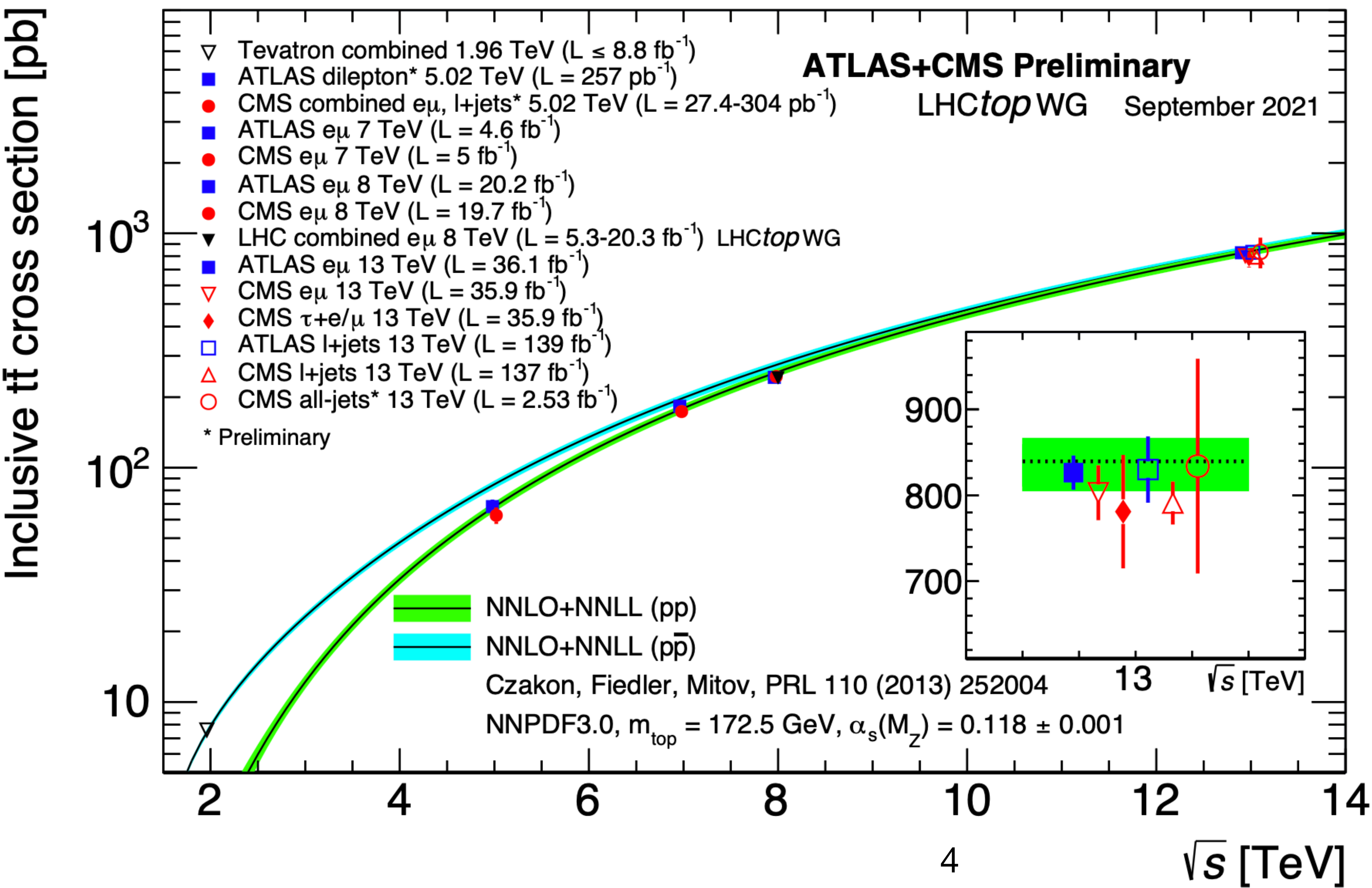
- Less precise
- Probe boosted top topologies



- Most precise channel
- Background:  $Wt$ , di-boson,  $z \rightarrow \tau^+\tau^-$

- High statistics
- Backgrounds:  $W$ +jets, Multi-jet
- Multiple control regions

# $t\bar{t}$ pair production



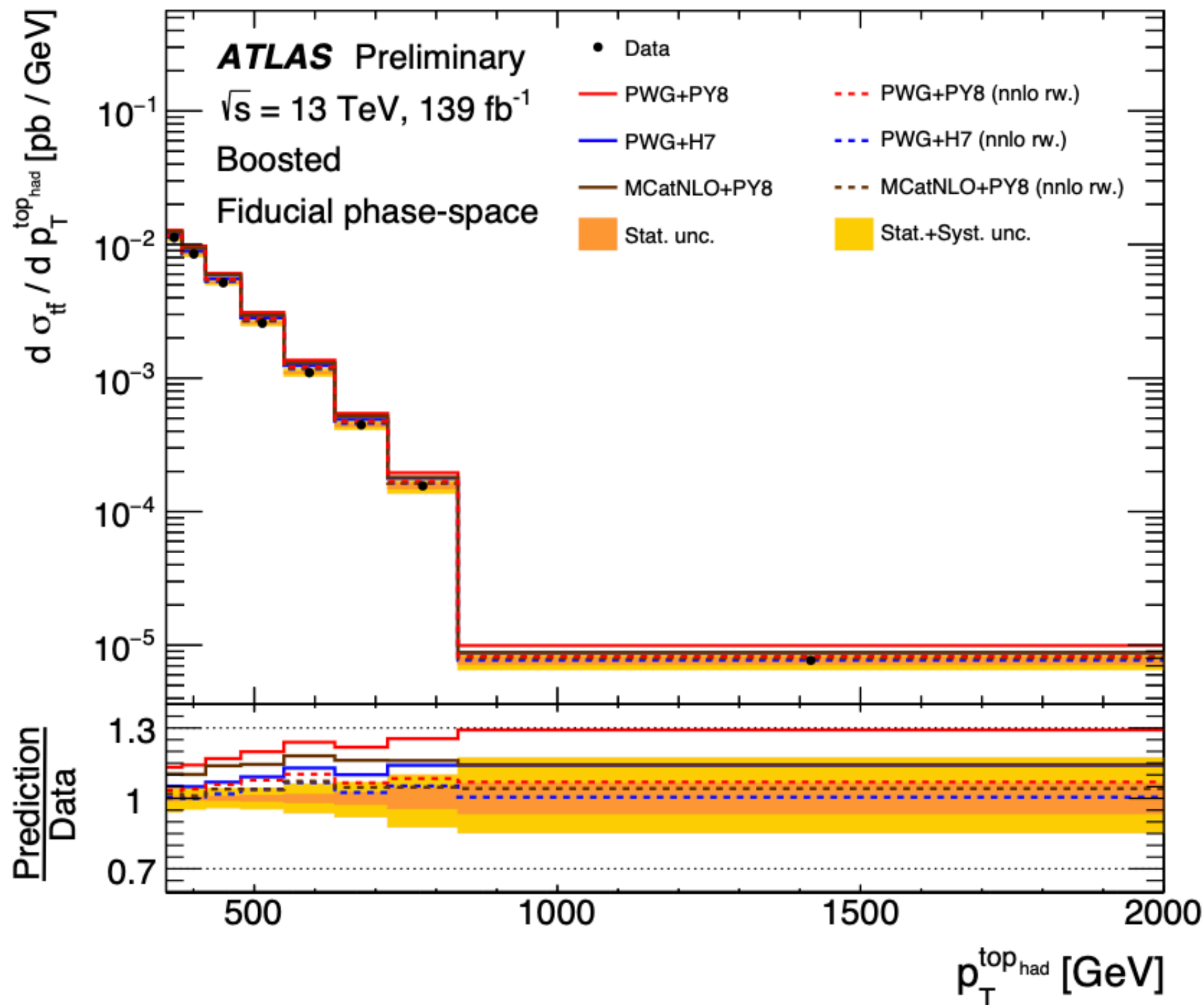
- Many measurements from ATLAS and CMS experiments at 5, 7, 8 and 13 TeV.
- Very good agreement between measurements and theory predictions



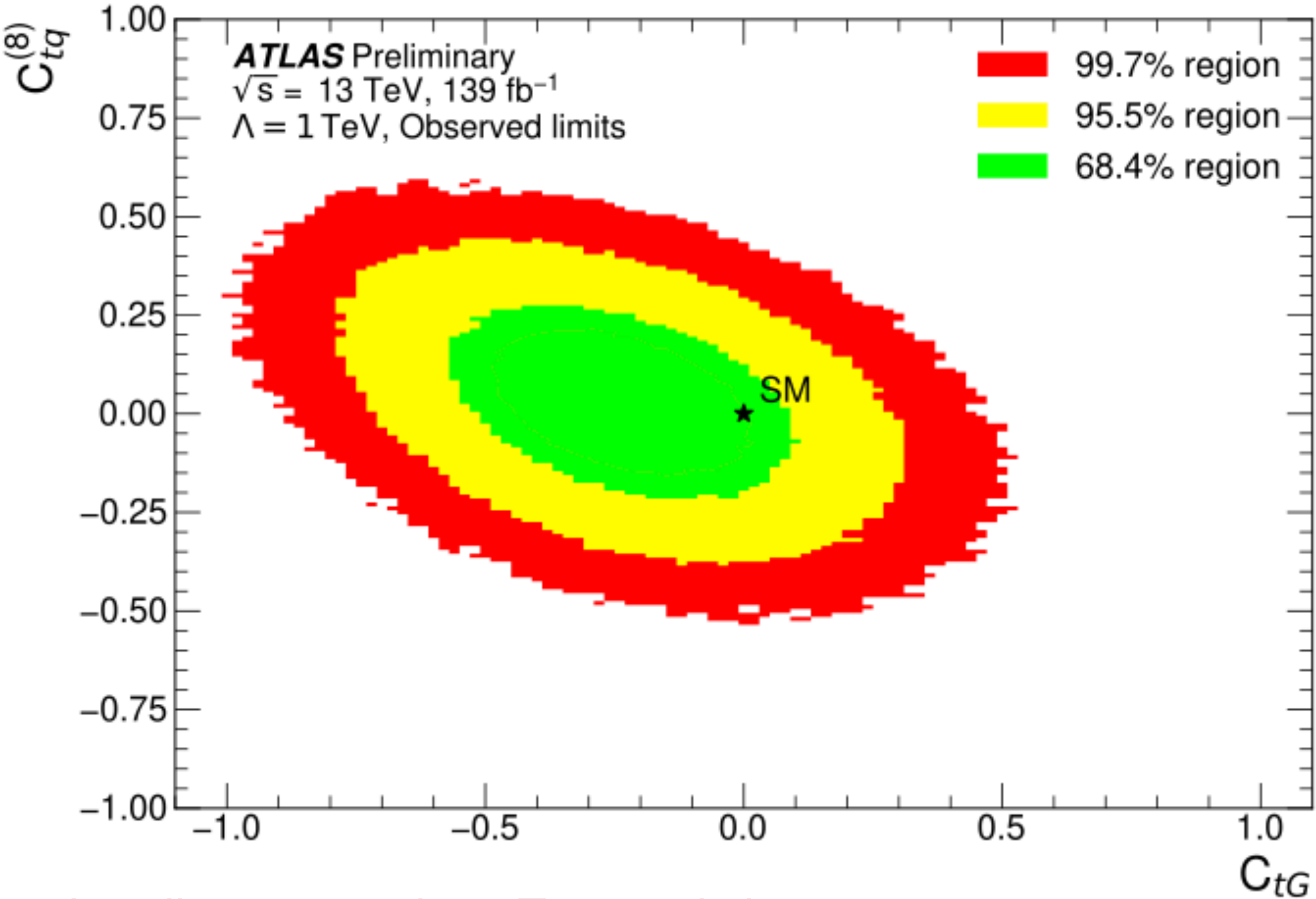
# $t\bar{t}$ pair production: Differential

ATLAS-CONF-2021-031

- Measurements (single, double and triple differential) in several kinematic variables available.
- Showing only results from l+jets analysis.
- Limits on Wilson coefficients of dim-6 EFT operators.



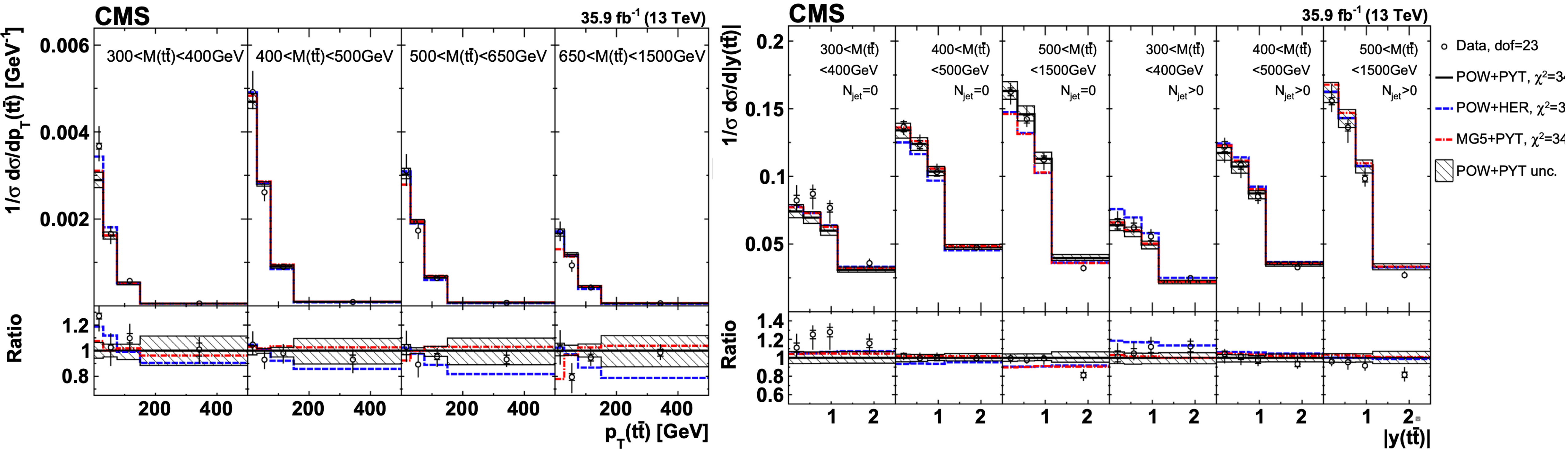
- NNLO corrections relevant: reweighted MC predictions shows good agreement with data.



- Leading uncertainty: Top modeling
- Jet uncertainties reduced by application of Jet Energy Scale Factors

# $t\bar{t}$ pair production: Differential

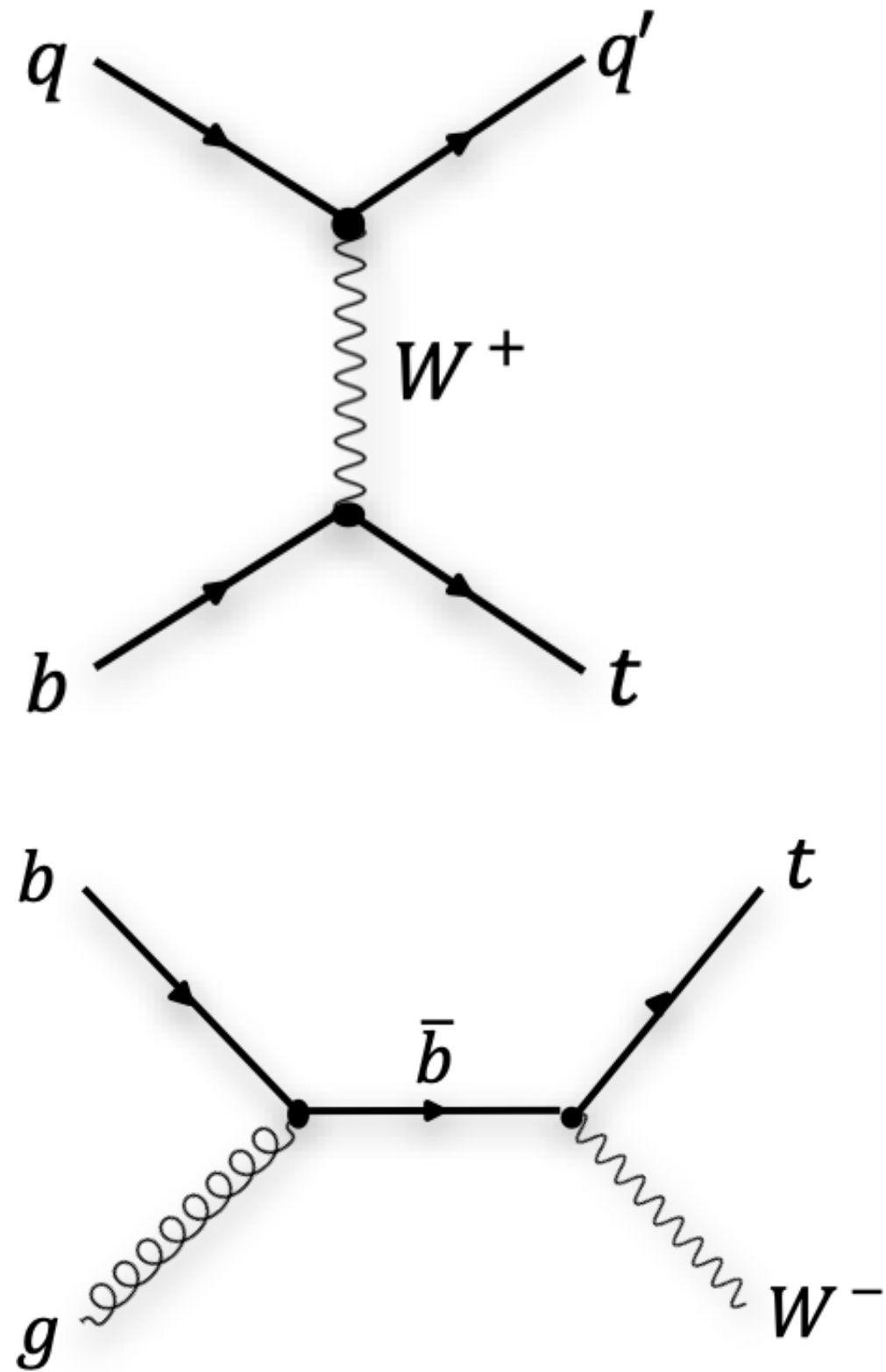
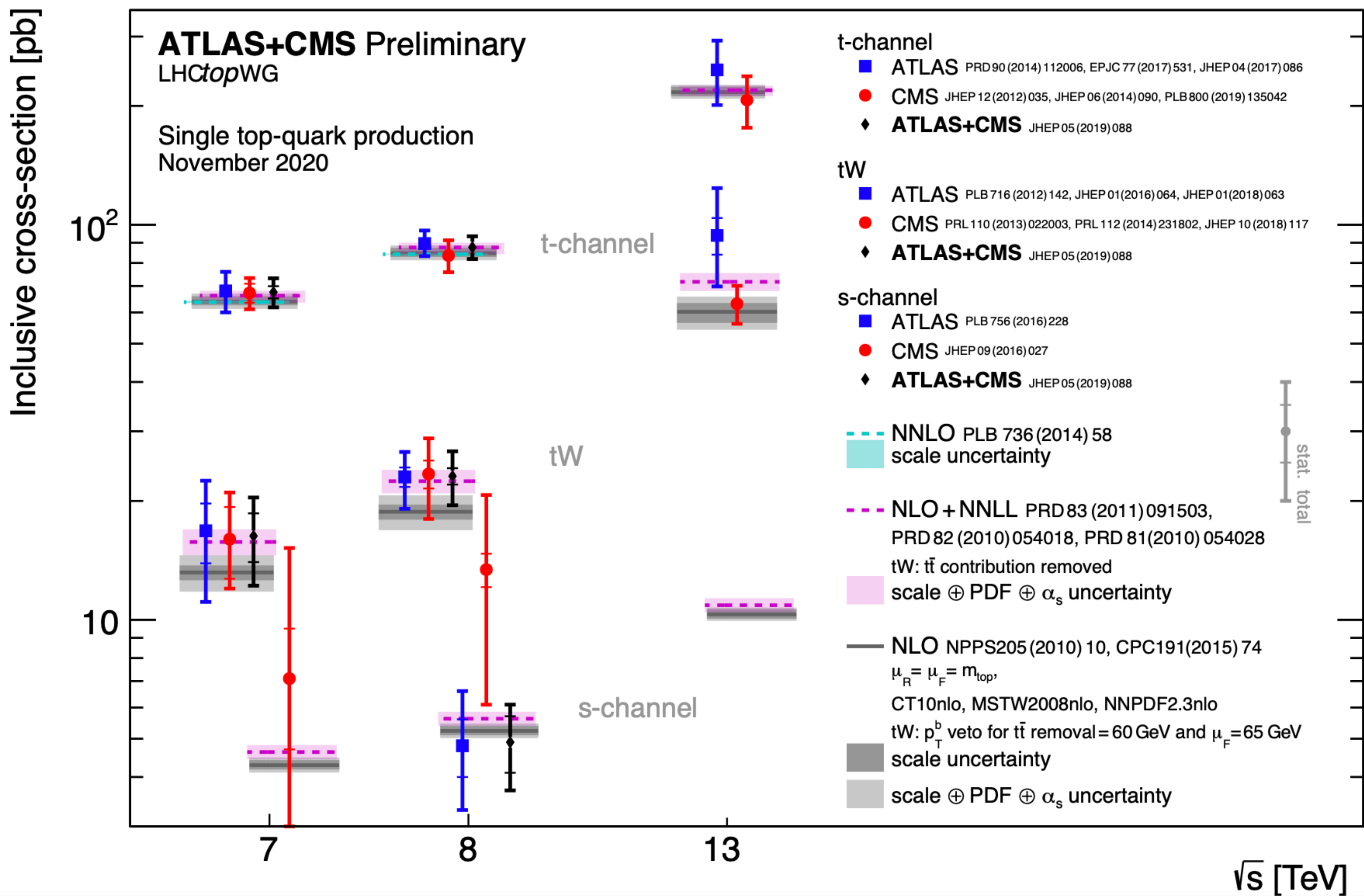
Eur. Phys. J. C 80 (2020) 658



- Combined  $ee + e\mu + \mu\mu$  OS channels
- Unfolded kinematic variables in various bins of invariant mass of  $t\bar{t}$  pair
- Good agreement for “POW+PYT” and “POW+HER”
- Total uncertainties are dominated by the systematic uncertainties. Largest uncertainty associated with Jet Energy Scale



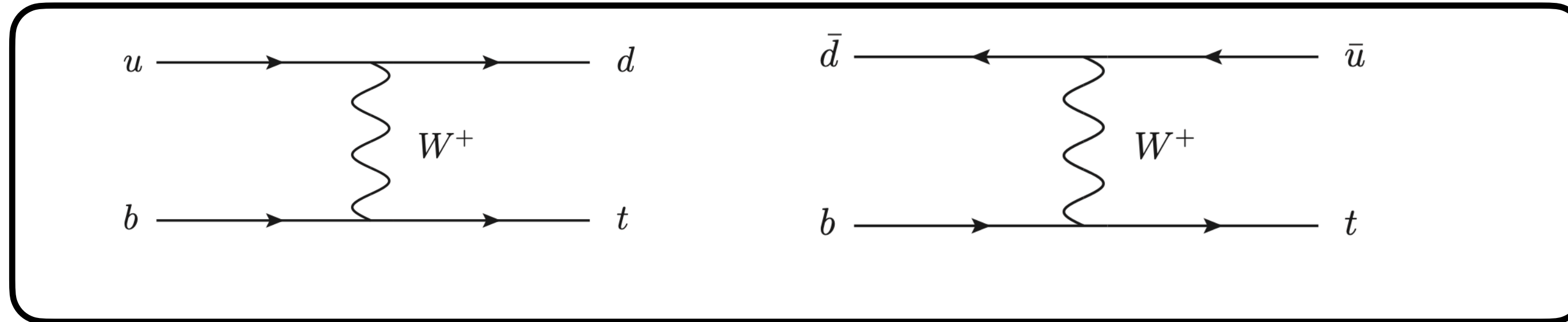
# Single top production



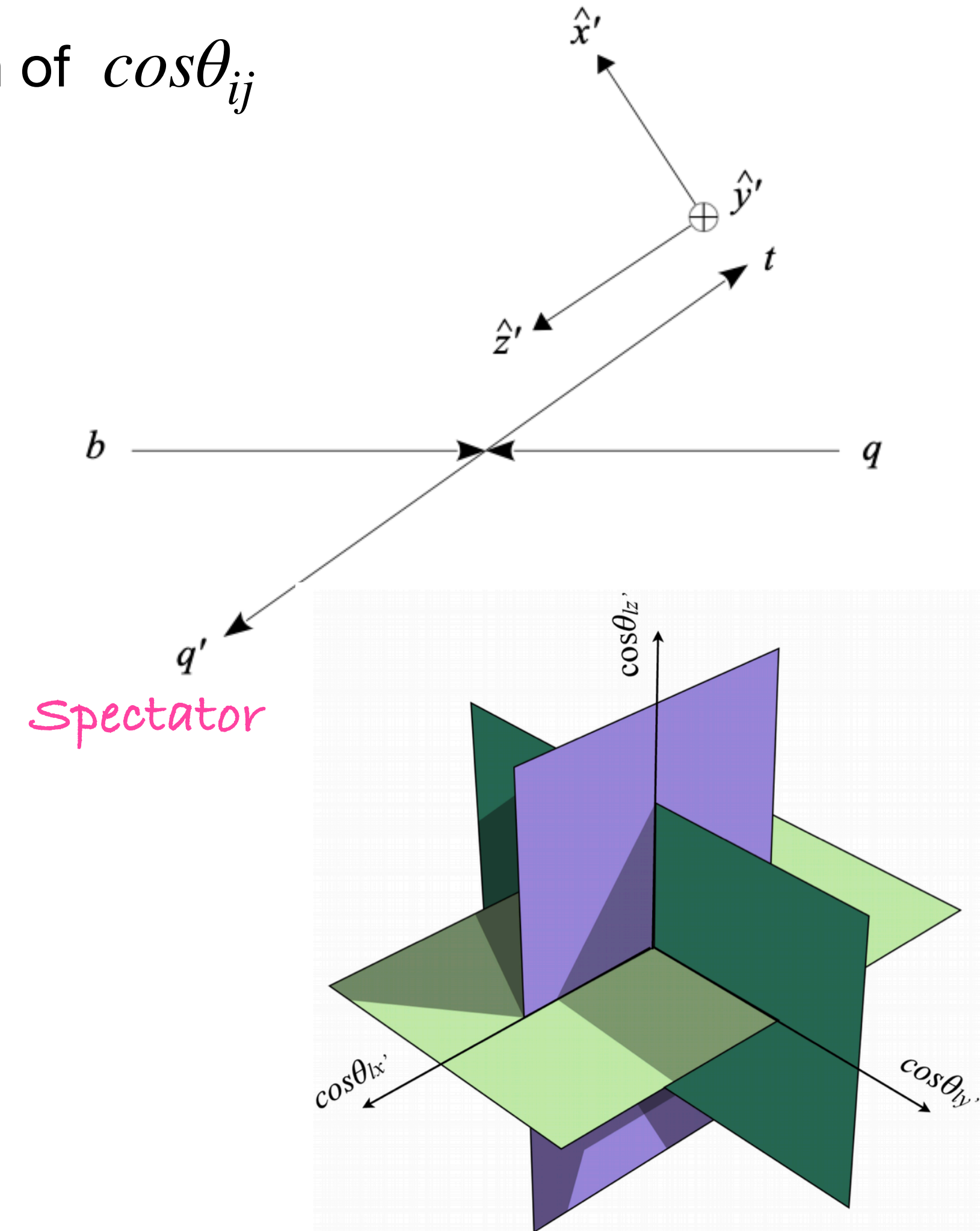
- Several measurements performed by ATLAS & CMS at 7, 8 & 13 TeV.
- Theory predictions in good agreement with measurement

# Single top: t-Channel, Polarization

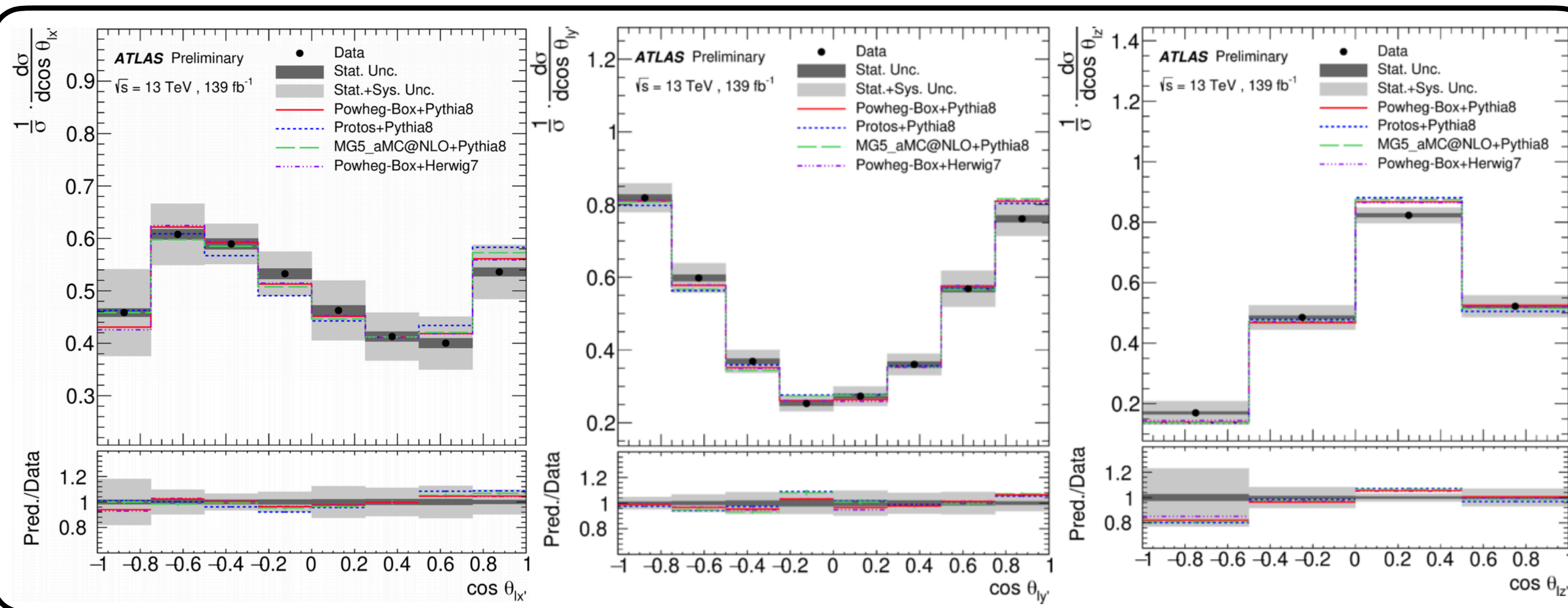
## Production



- Top quark in t-channel single top production is polarized.
- Polarization vector is extracted as a function of  $\cos\theta_{ij}$

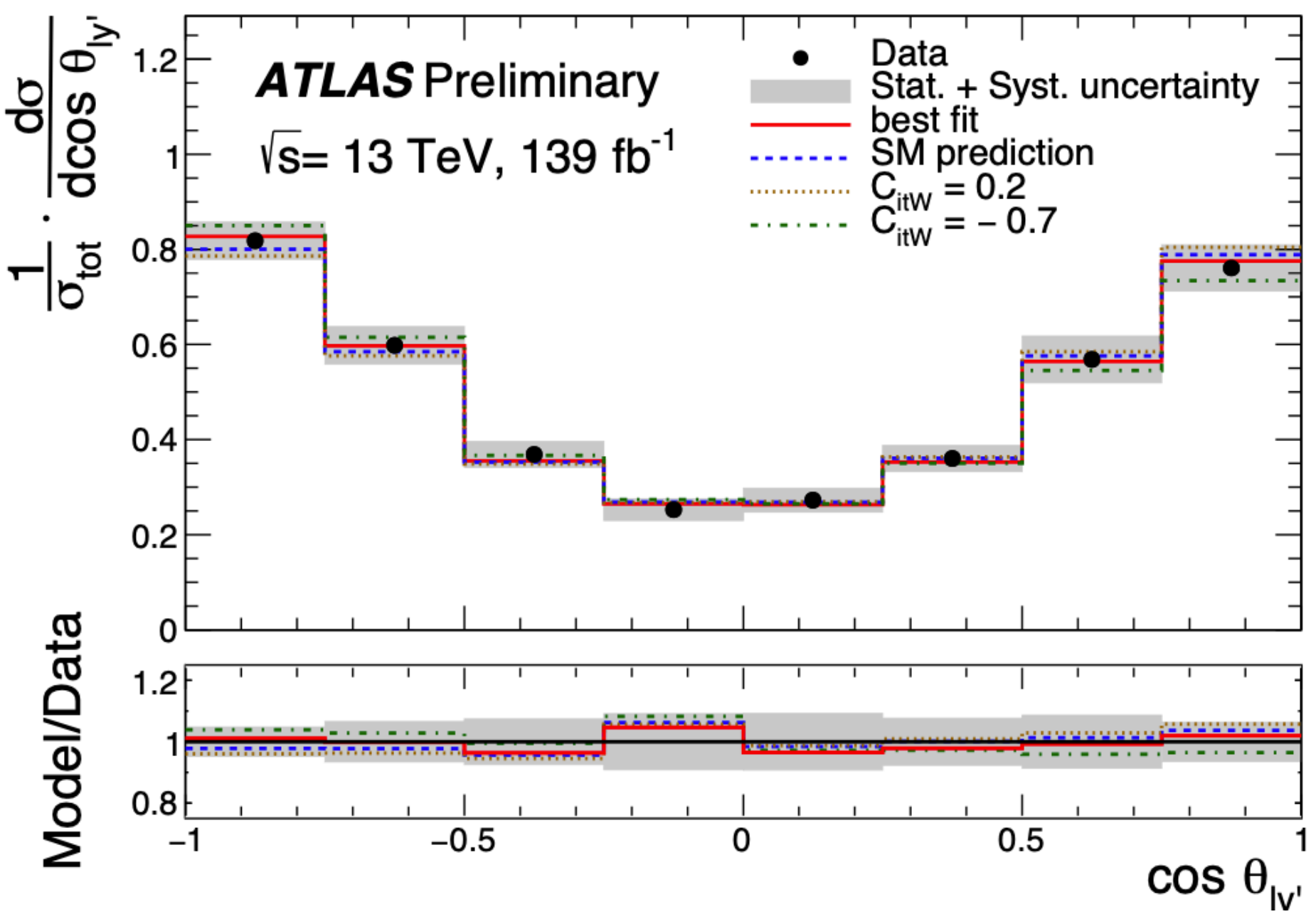
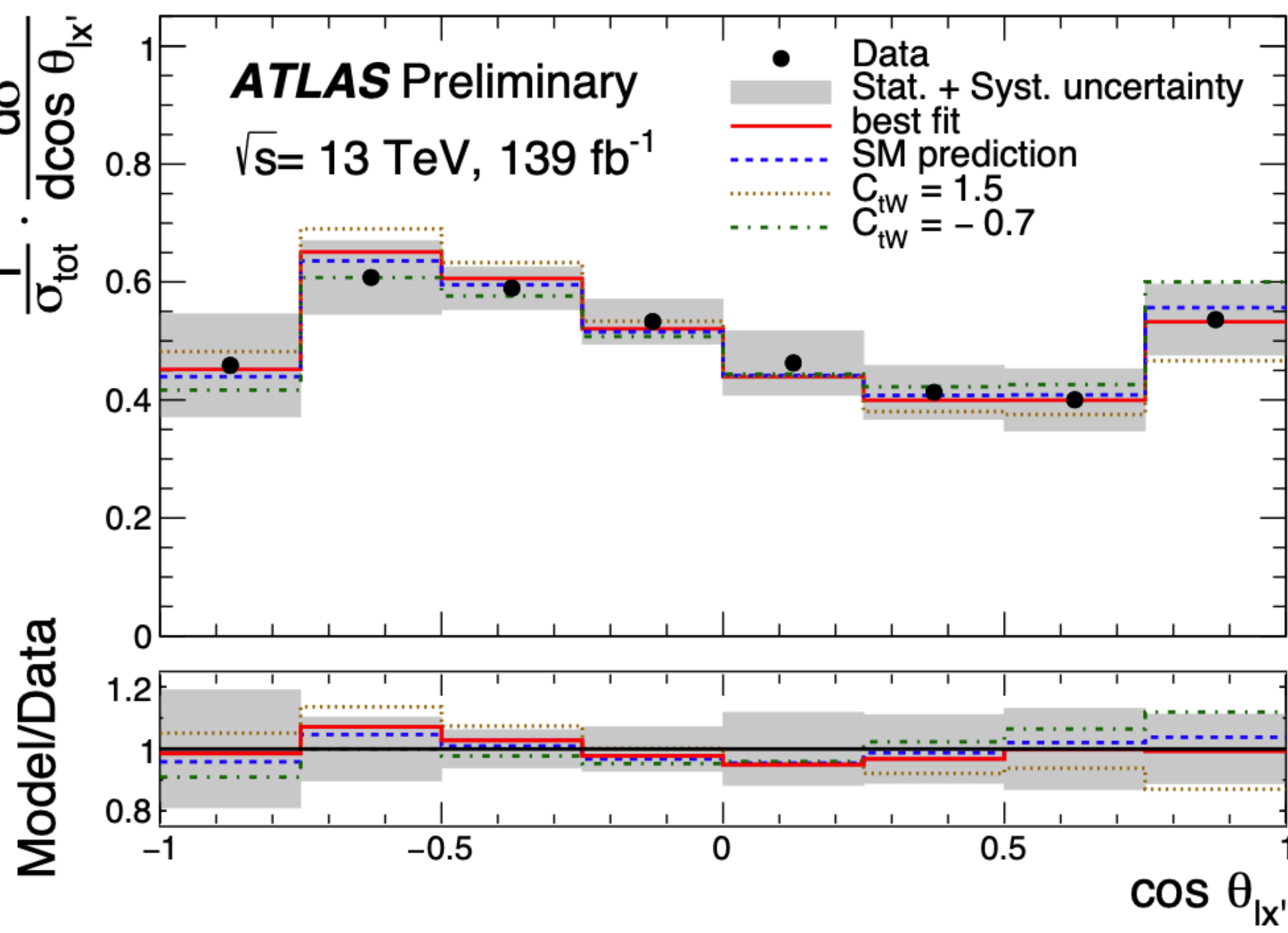


## Unfolded direction cosines





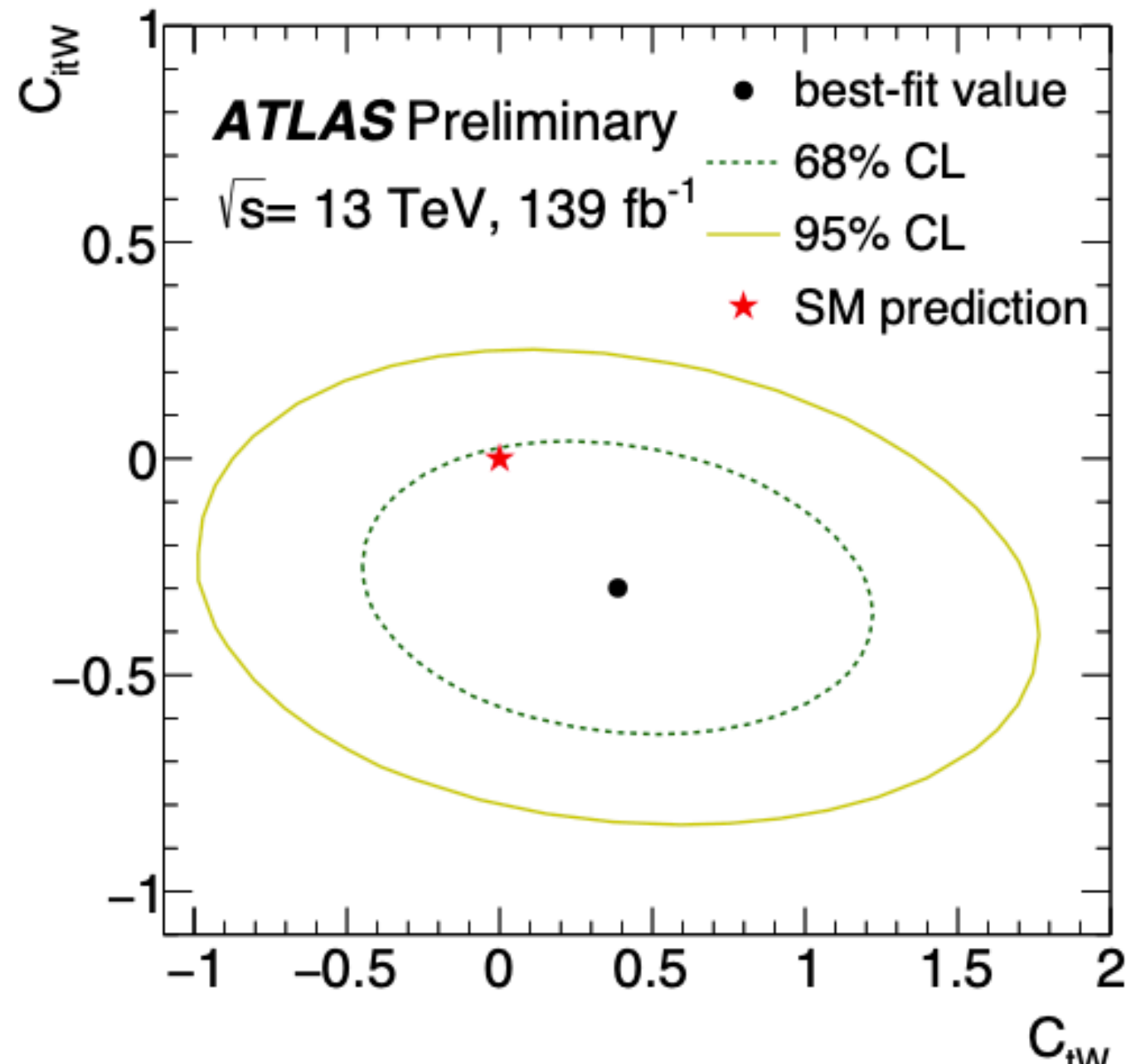
# Single top: t-Channel, Polarization (EFT interpretation)



- Leading uncertainties:
  - Jet Energy scale & Resolution

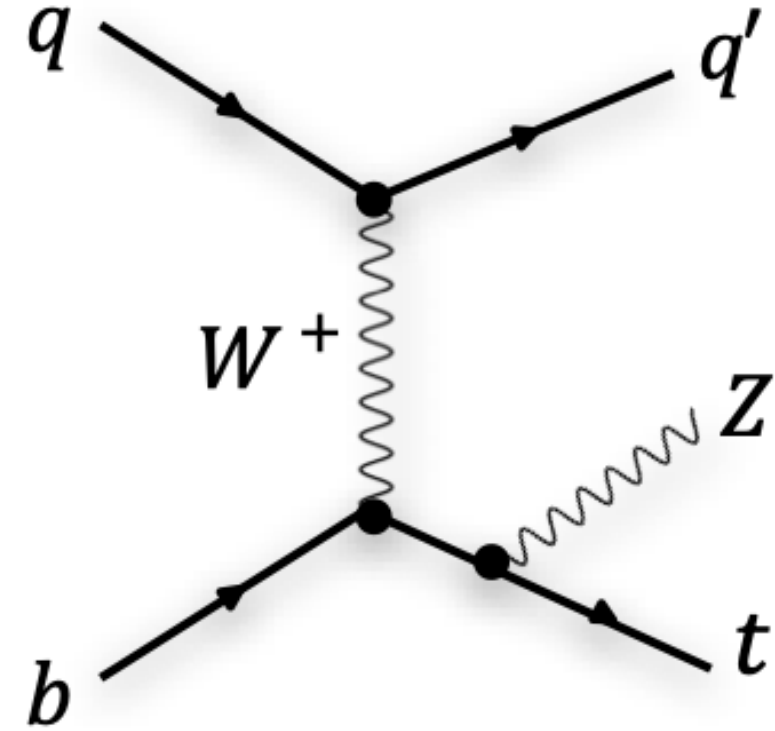
- Dim-6 EFT operator coefficients ( $\mathcal{O}_{tW}$ ) extracted.

	$C_{tW}$		$C_{itW}$	
	68% CL	95% CL	68% CL	95% CL
All terms	[-0.2, 0.9]	[-0.7, 1.5]	[-0.5, -0.1]	[-0.7, 0.2]
Order $1/\Lambda^4$	[-0.2, 0.9]	[-0.7, 1.5]	[-0.5, -0.1]	[-0.7, 0.2]
Order $1/\Lambda^2$	[-0.2, 1.0]	[-0.7, 1.7]	[-0.5, -0.1]	[-0.8, 0.2]

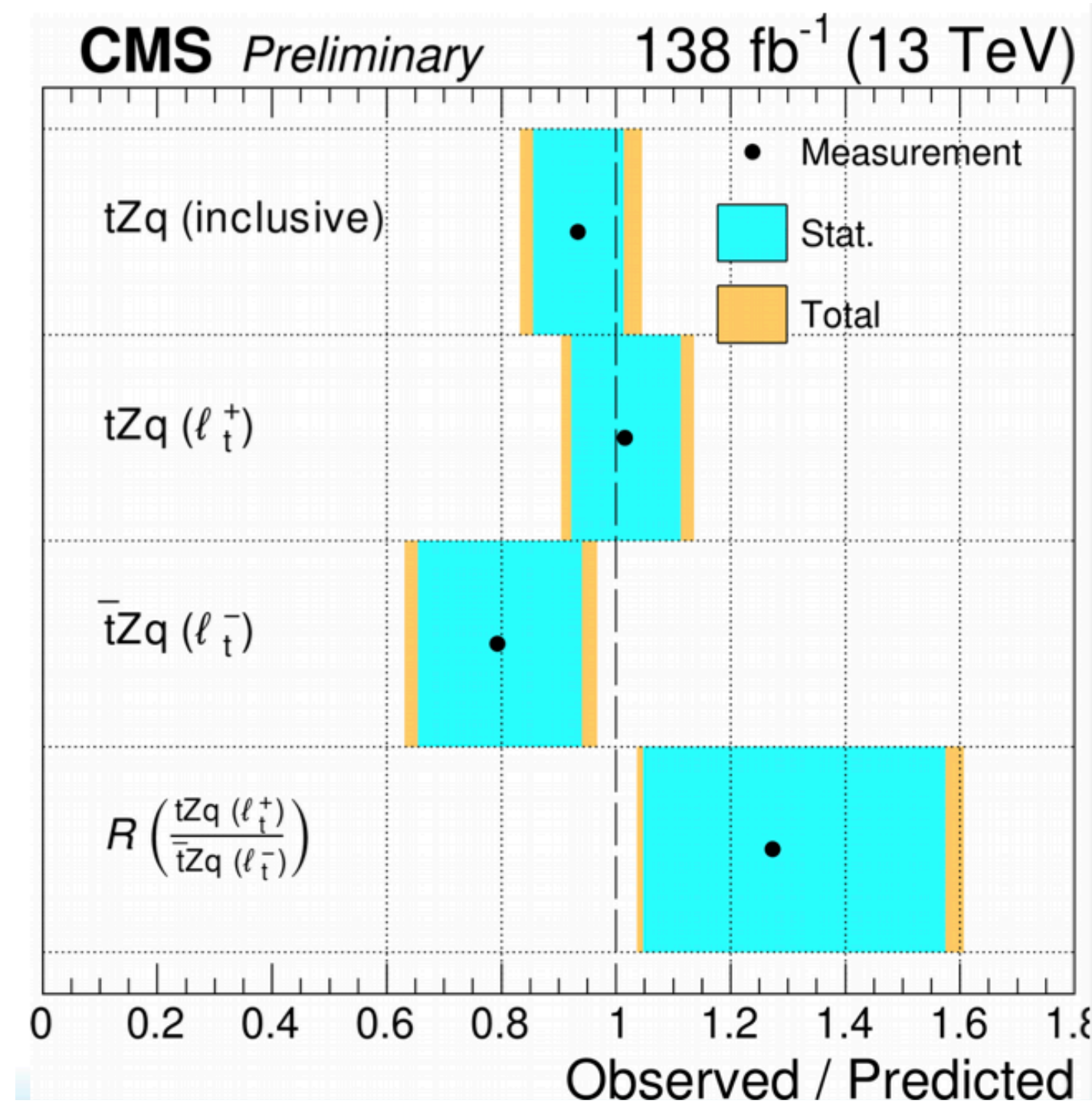


# $tZq$ : Differential and inclusive measurement

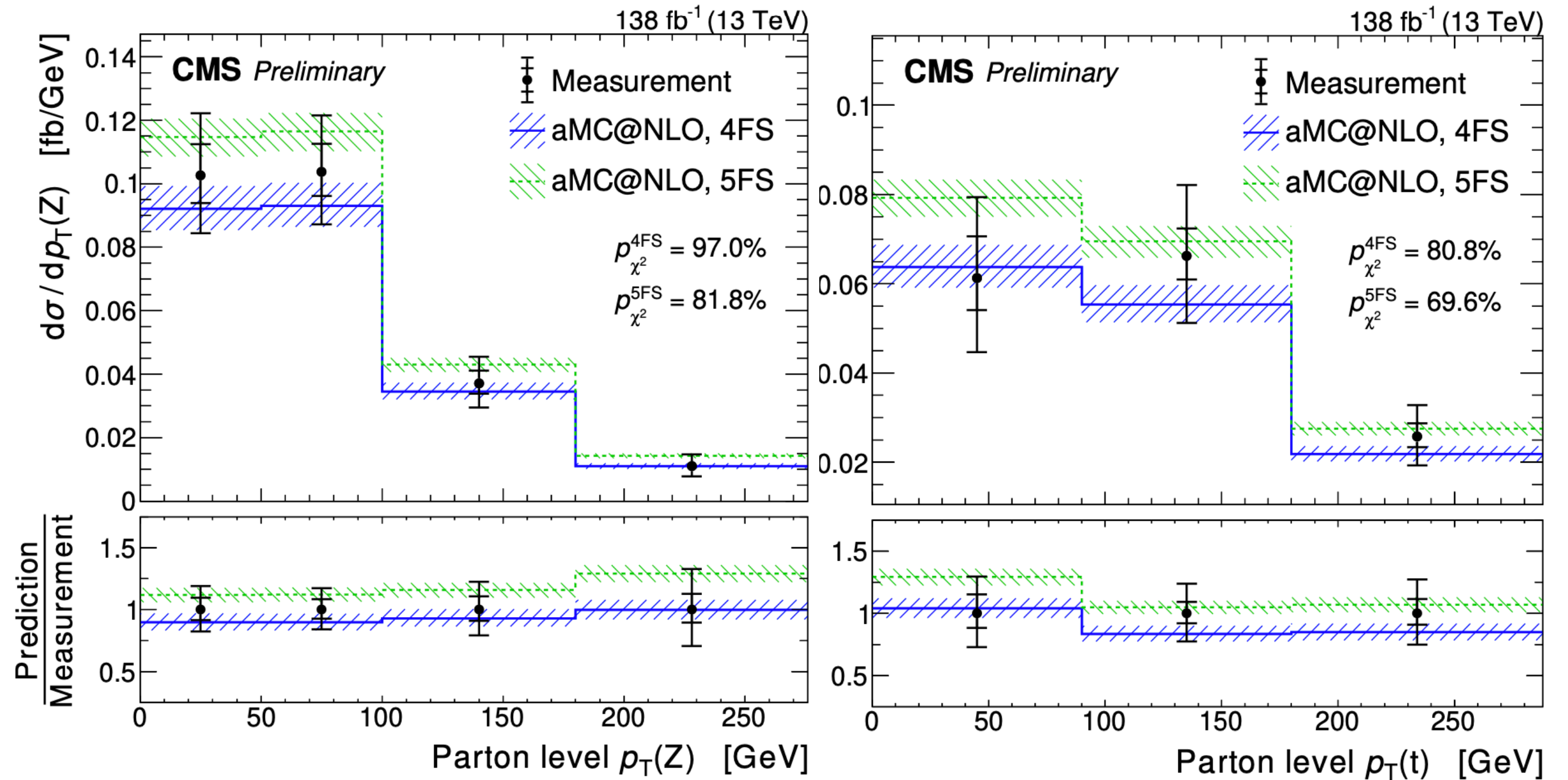
CMS-PAS-TOP-20-010



- Only small QCD corrections. Precise  $tZ$  coupling measurement possible



- Systematics are dominated by signal and  $t\bar{t}Z$  scale variations.



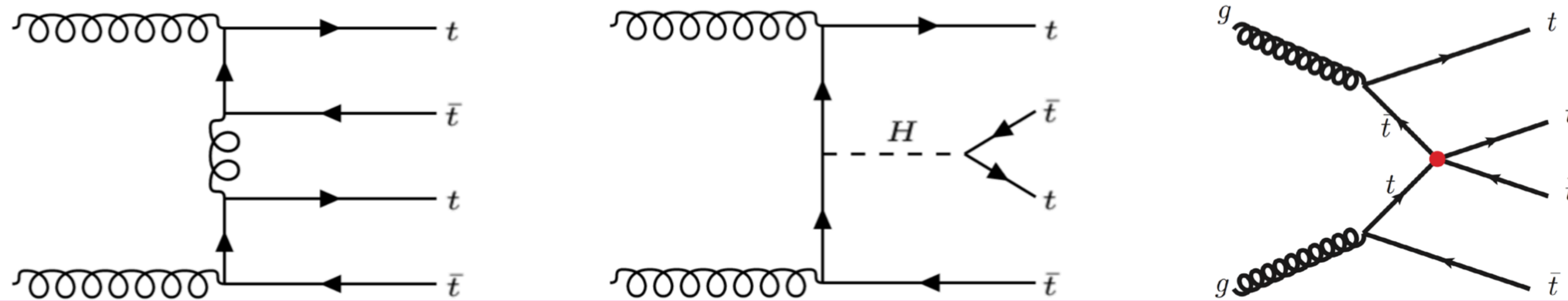
- 5FS predicts larger cross-section wrt 4FS. However the results are compatible within uncertainties.
- Inclusive measurement from ATLAS: [J. High Energ. Phys. 2020, 124 \(2020\)](#)



# Rare process: $t\bar{t}t\bar{t}$ production

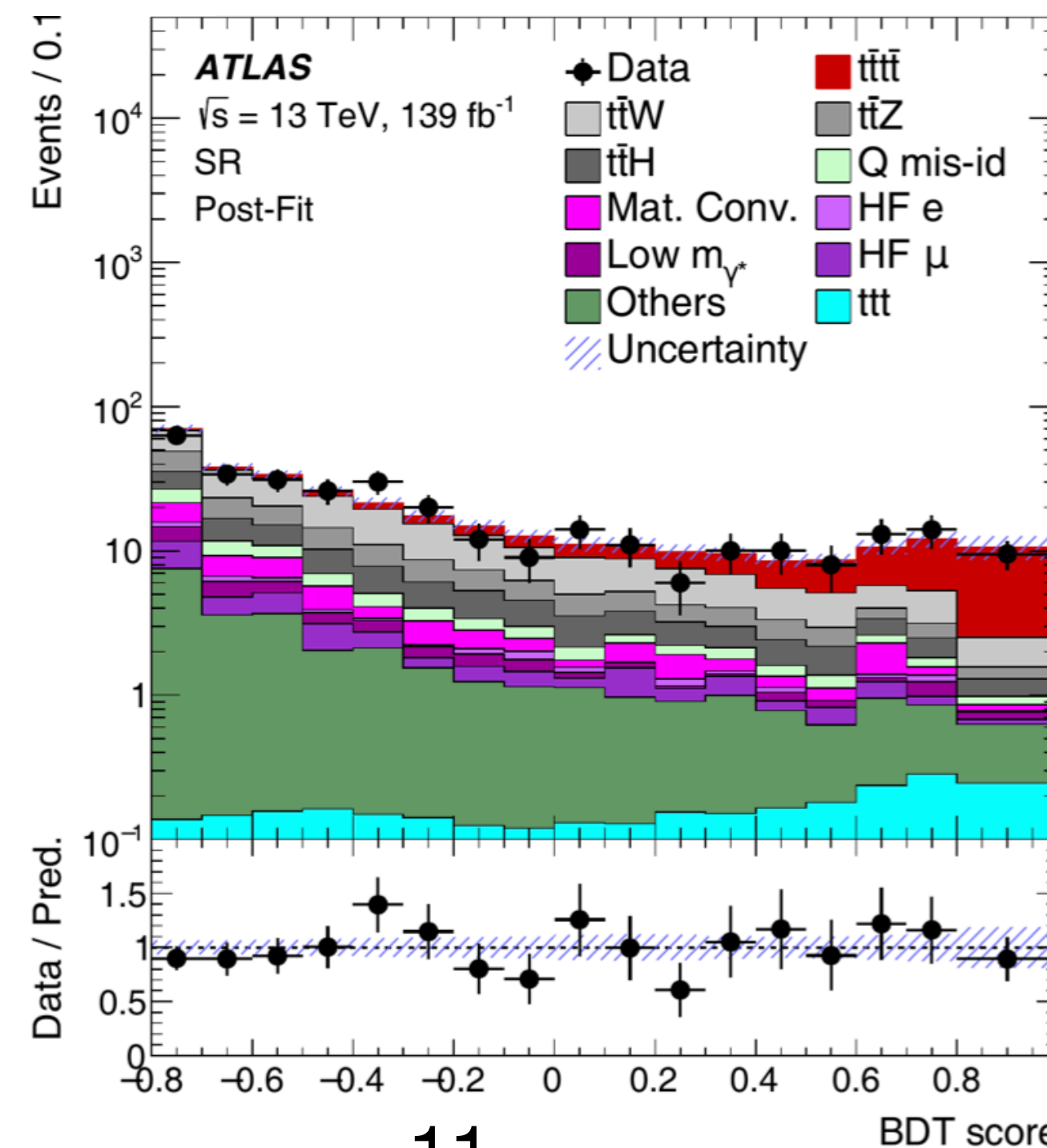
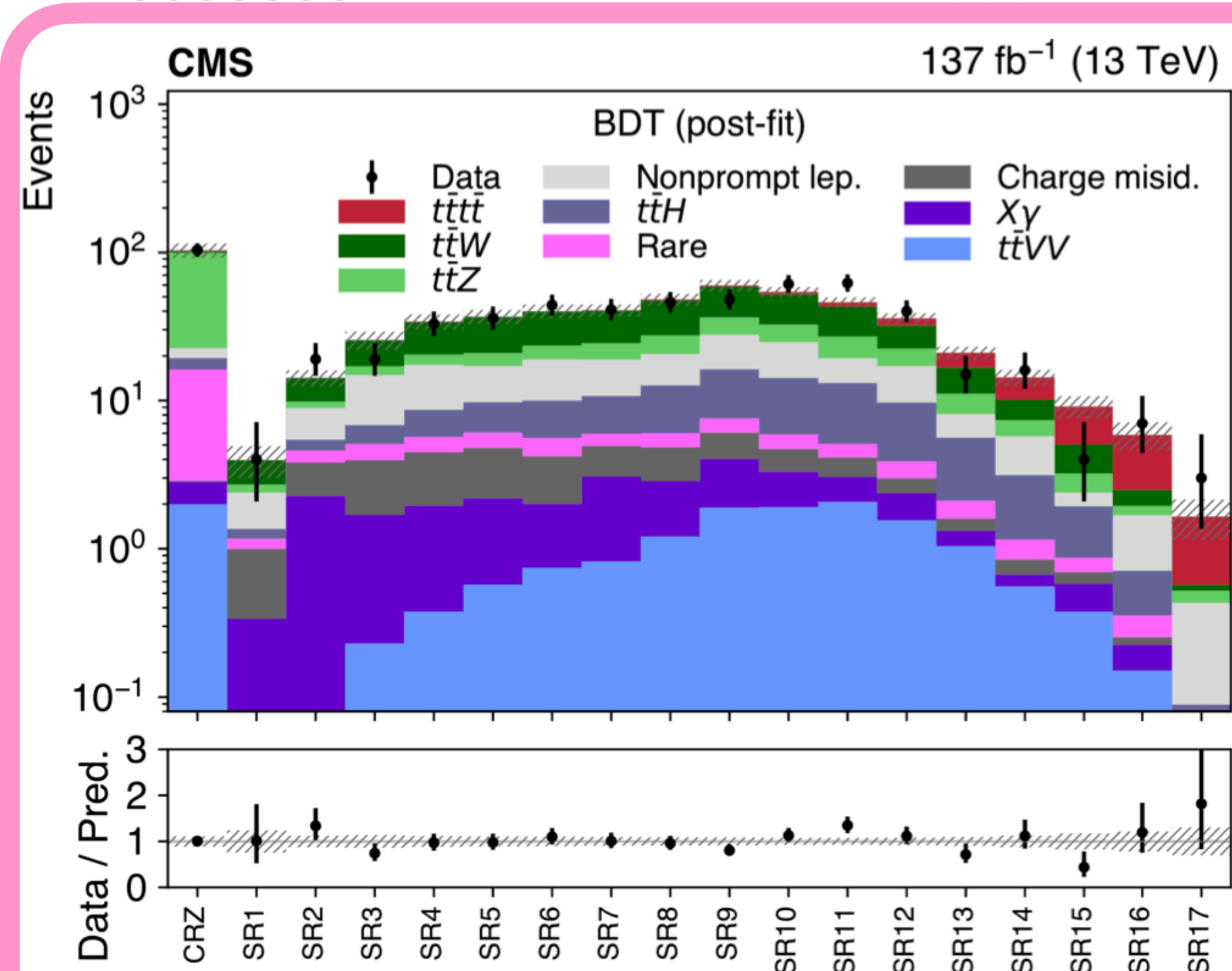
**First Evidence from ATLAS**

- Enhancement to the cross-section is expected from BSM contributions
- Diagram with offshell Higgs sensitive to top Yukawa coupling



- High multiplicity final state: 4 b-jets, light jets and leptons
- Channels defined by lepton multiplicity and charge

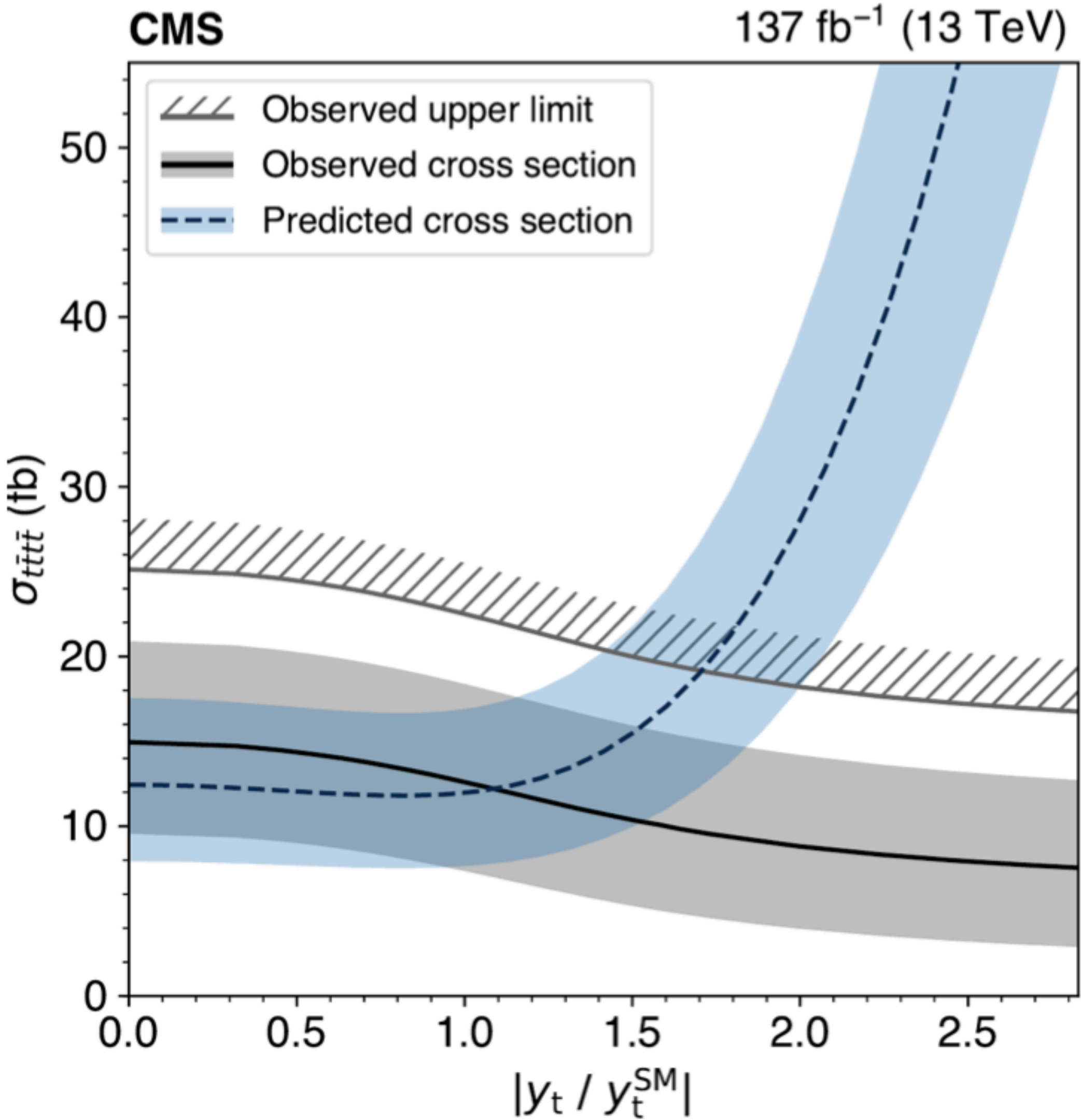
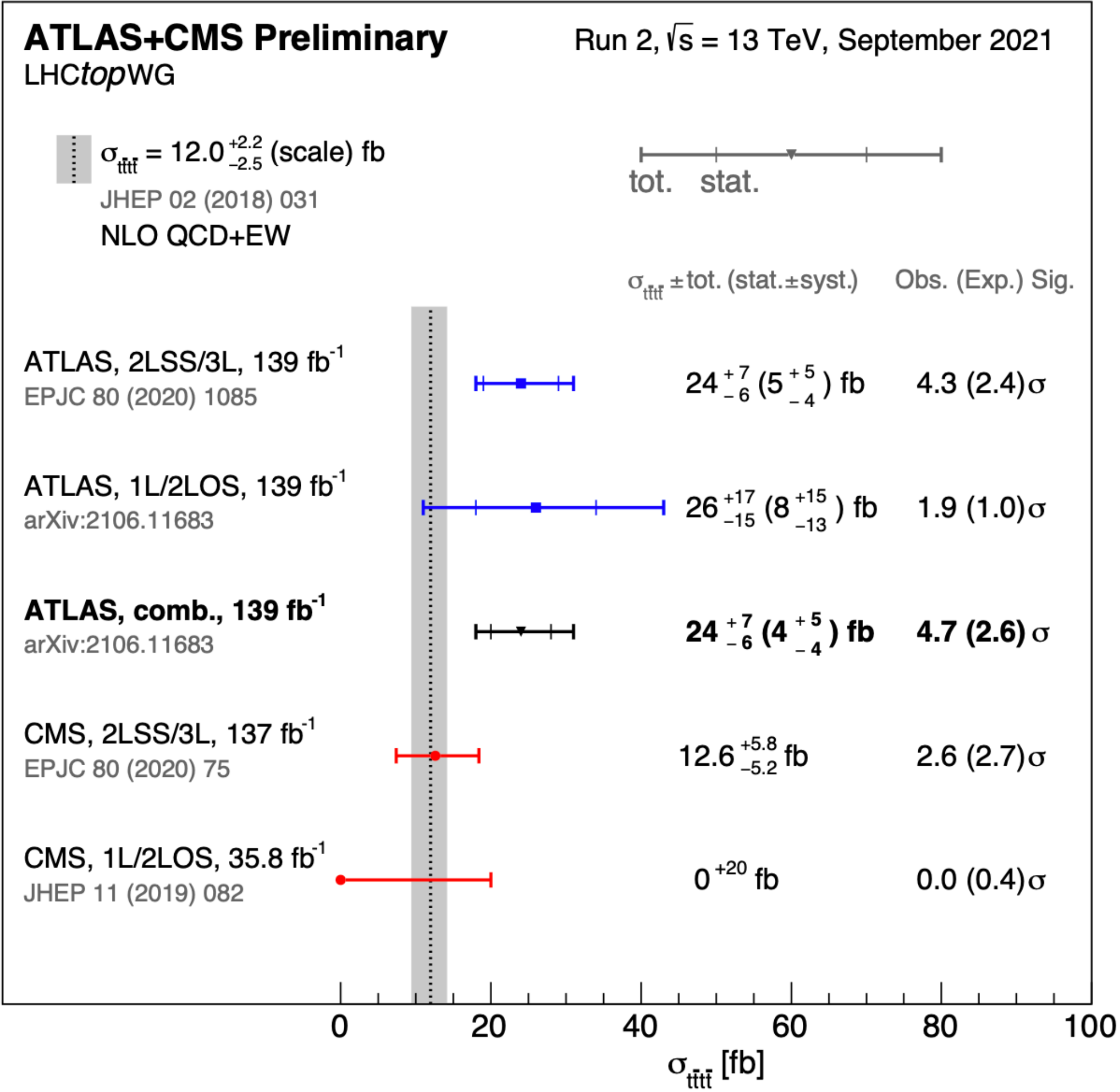
Channel	Branching ratio
$0\ell$	31%
$1\ell$	42%
$2\ell(\text{SS})$	14%
$2\ell(\text{OS})$	7%
$\geq 3\ell$	5%



Leading uncertainties:

- $t\bar{t}X$  modeling, Jet, b-tagging and signal modeling

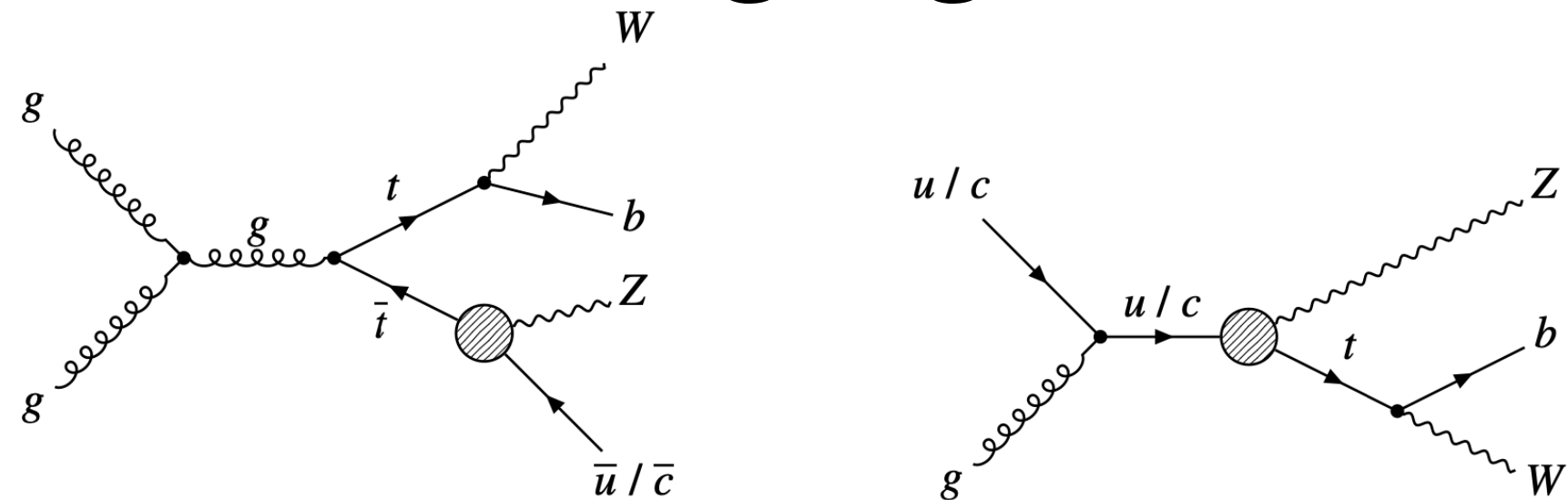
# Rare process: $t\bar{t}t\bar{t}$ production



- All analyses and combinations compatible with Standard model prediction.

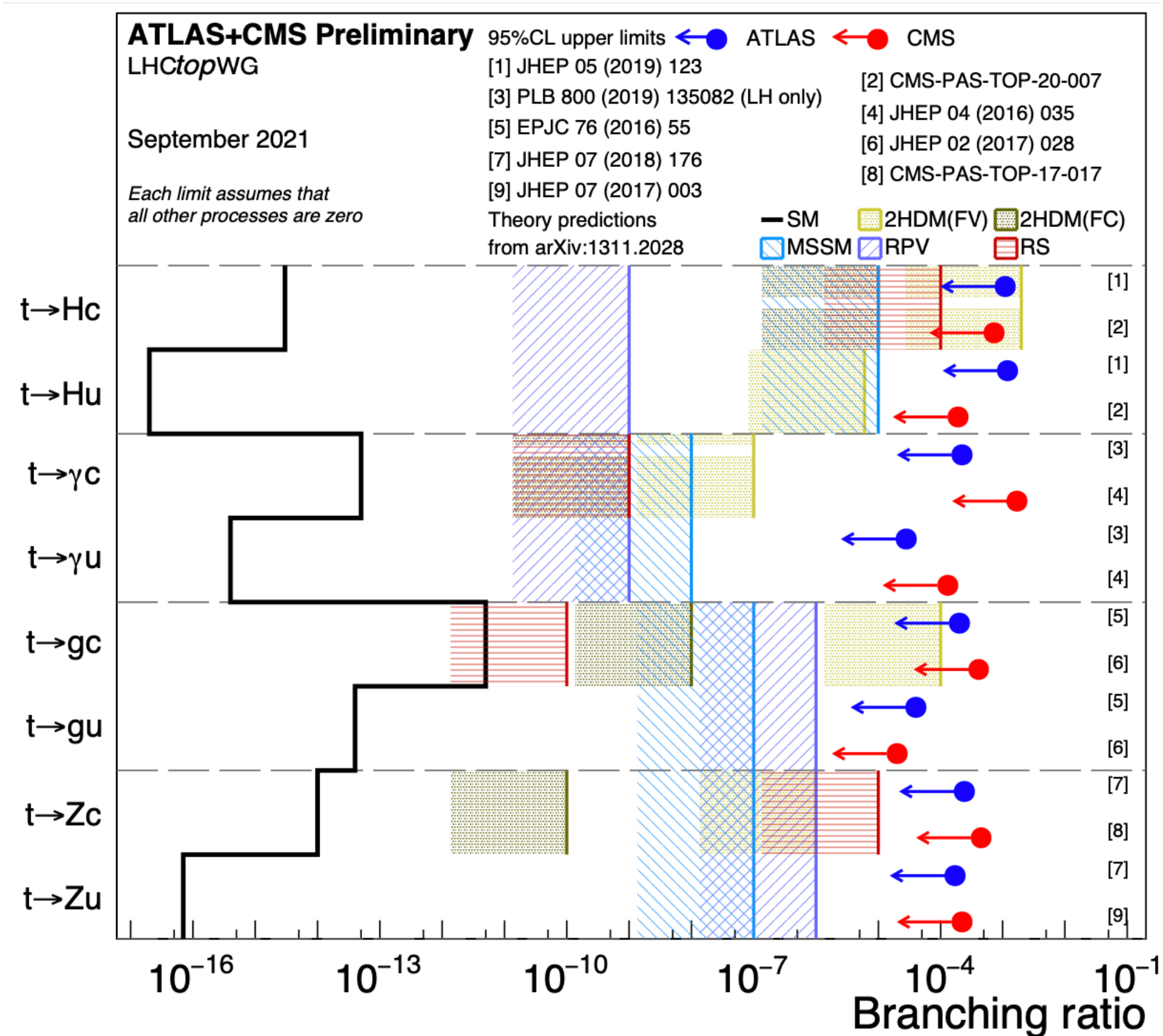


# Flavour changing neutral currents



ATLAS-CONF-2021-049

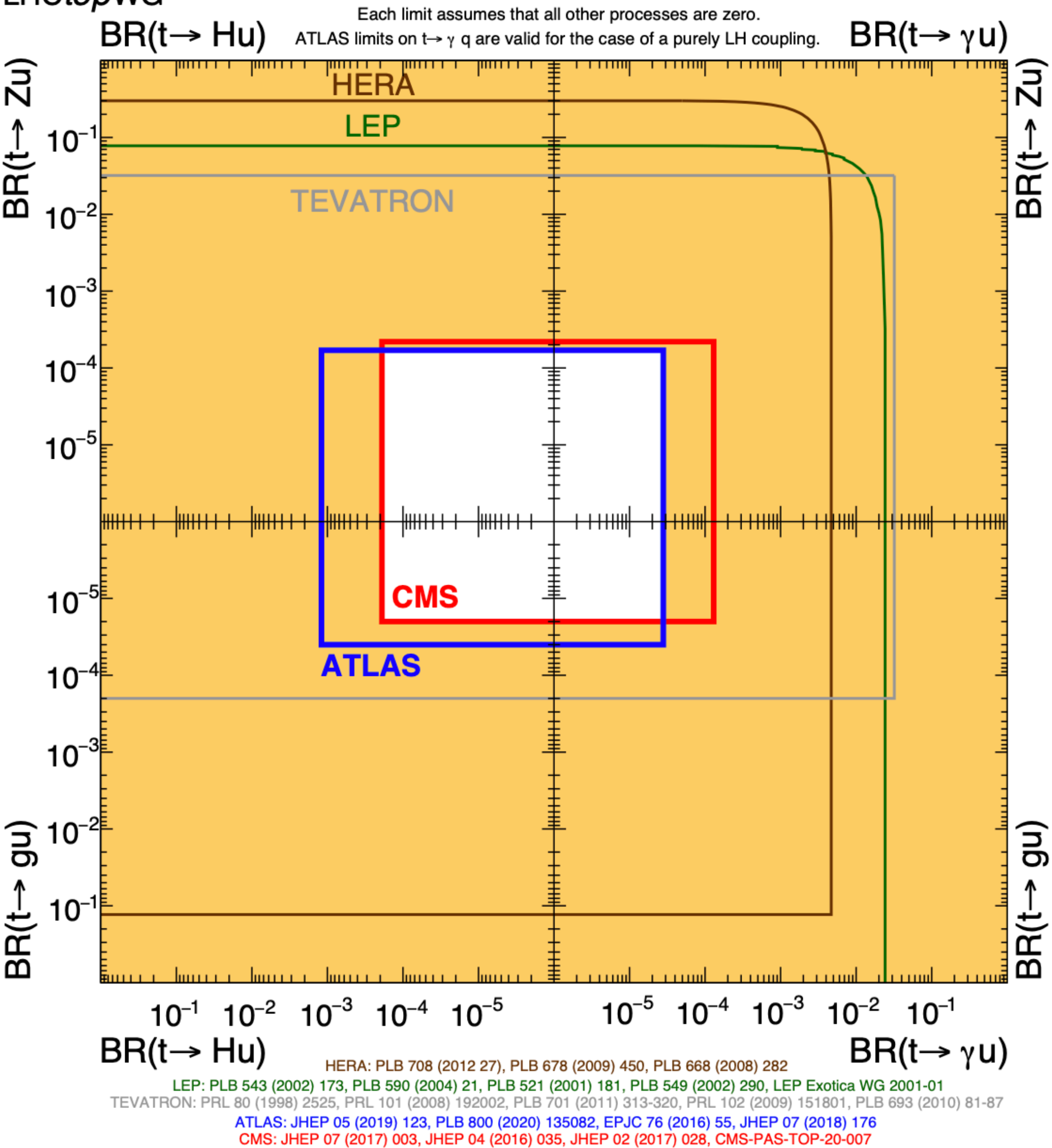
- Forbidden in SM at tree level and suppressed at NLO



Most stringent limit  $BR(t \rightarrow zu) : 6.2 \times 10^{-5}$

ATLAS+CMS Preliminary  
LHCtopWG

September 2021



# Conclusion

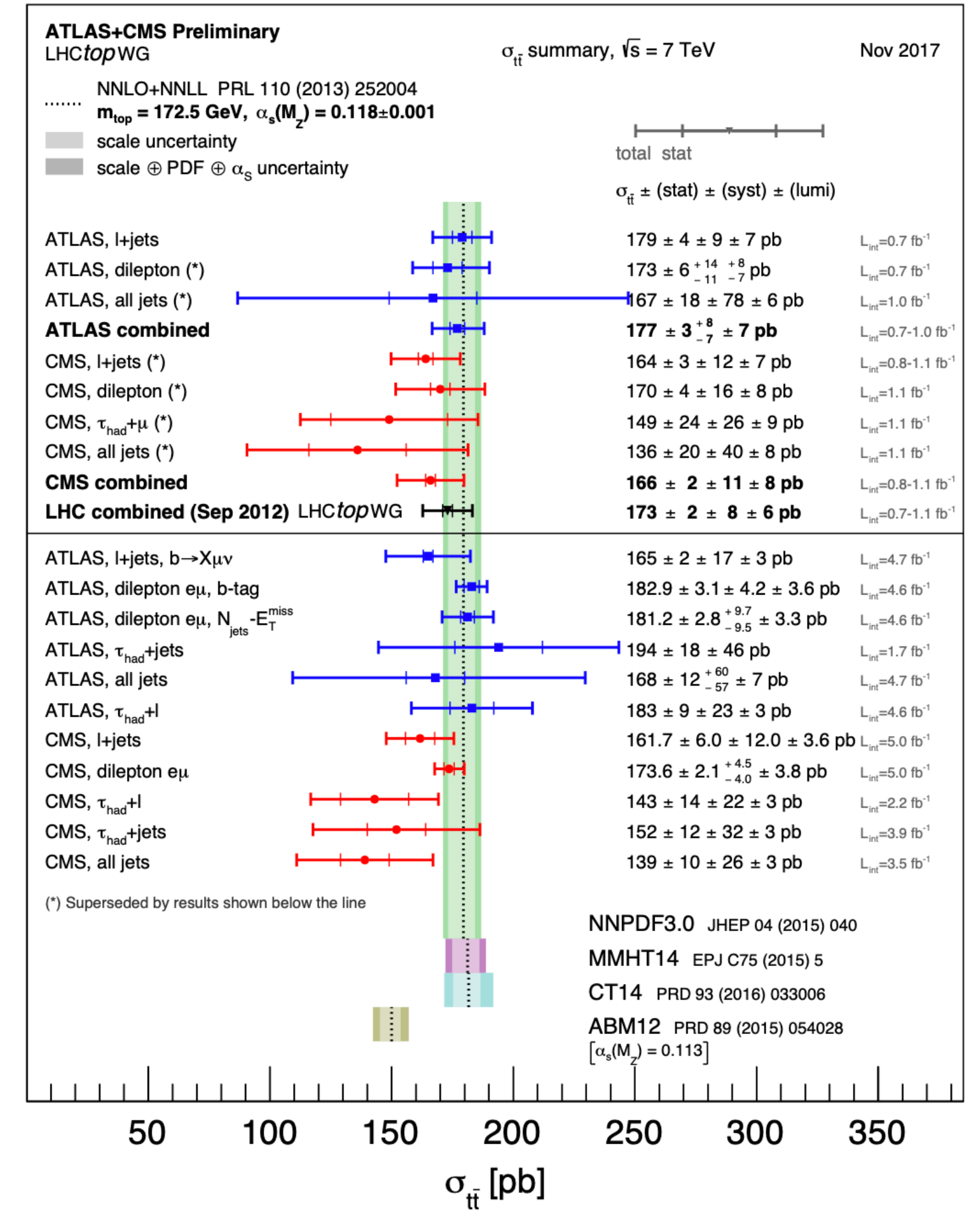
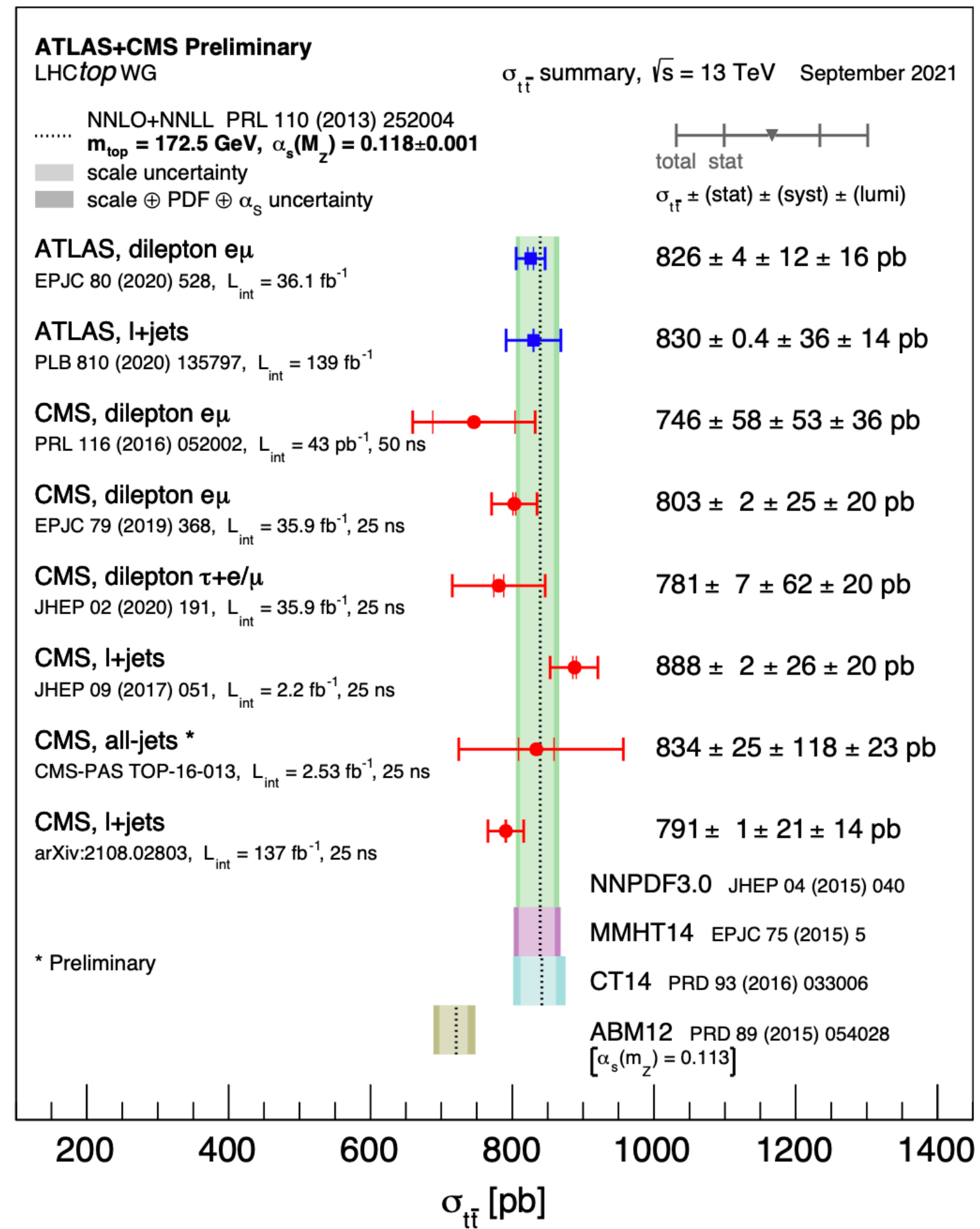
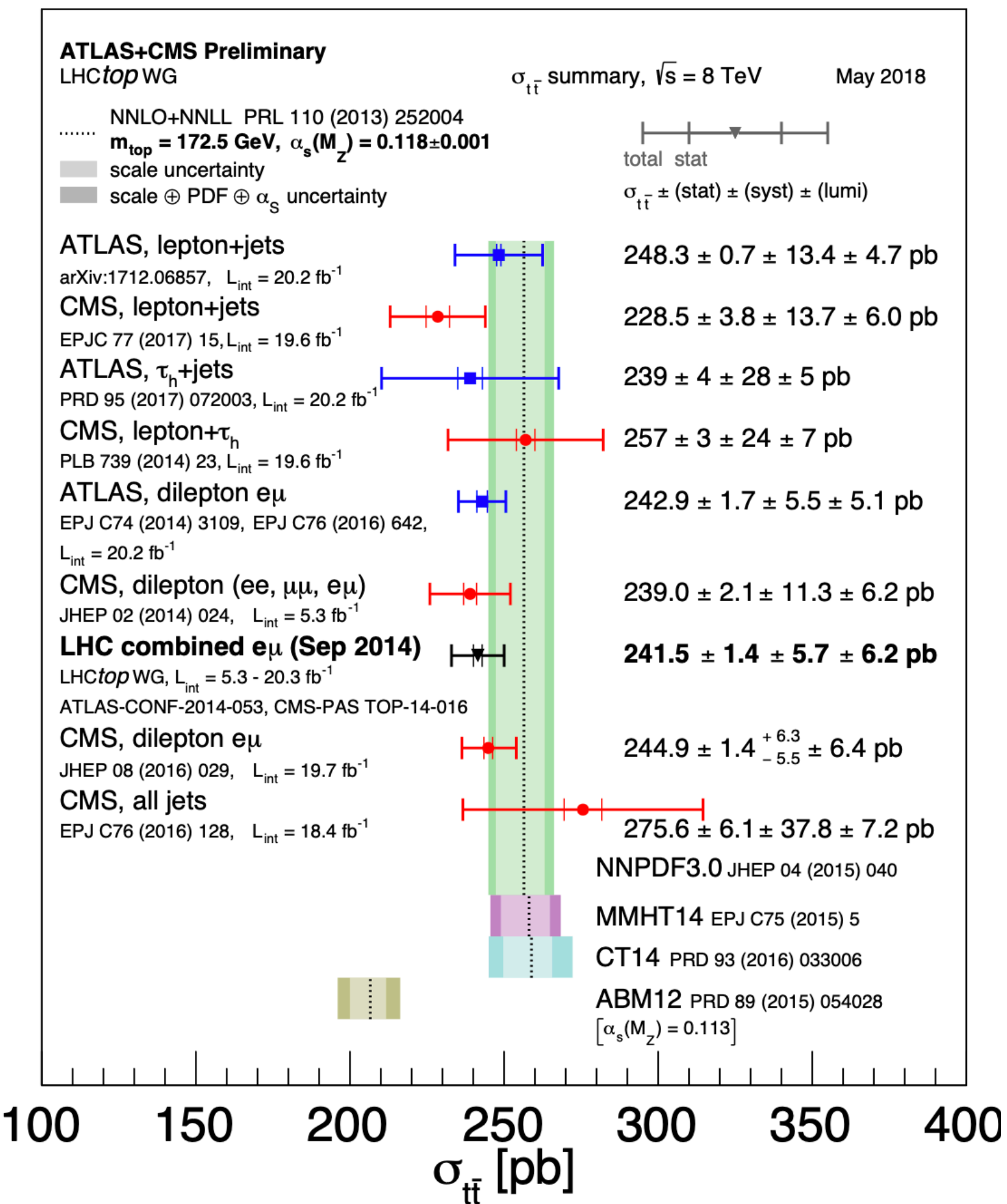
- With LHC delivering millions of top quark events, top physics has entered **precision measurement** era
  - ATLAS + CMS performed many precision measurements
- Recent measurements agree with the Standard model quite well
  - Probed rare processes like the **4-top** production
  - More precise and **differential** measurements
- Understanding of detector and physics modeling
  - Largest experimental uncertainty from **Jet energy scale uncertainty**
  - Theory uncertainty limited by modeling of **parton shower and hadronization**

**Backup**



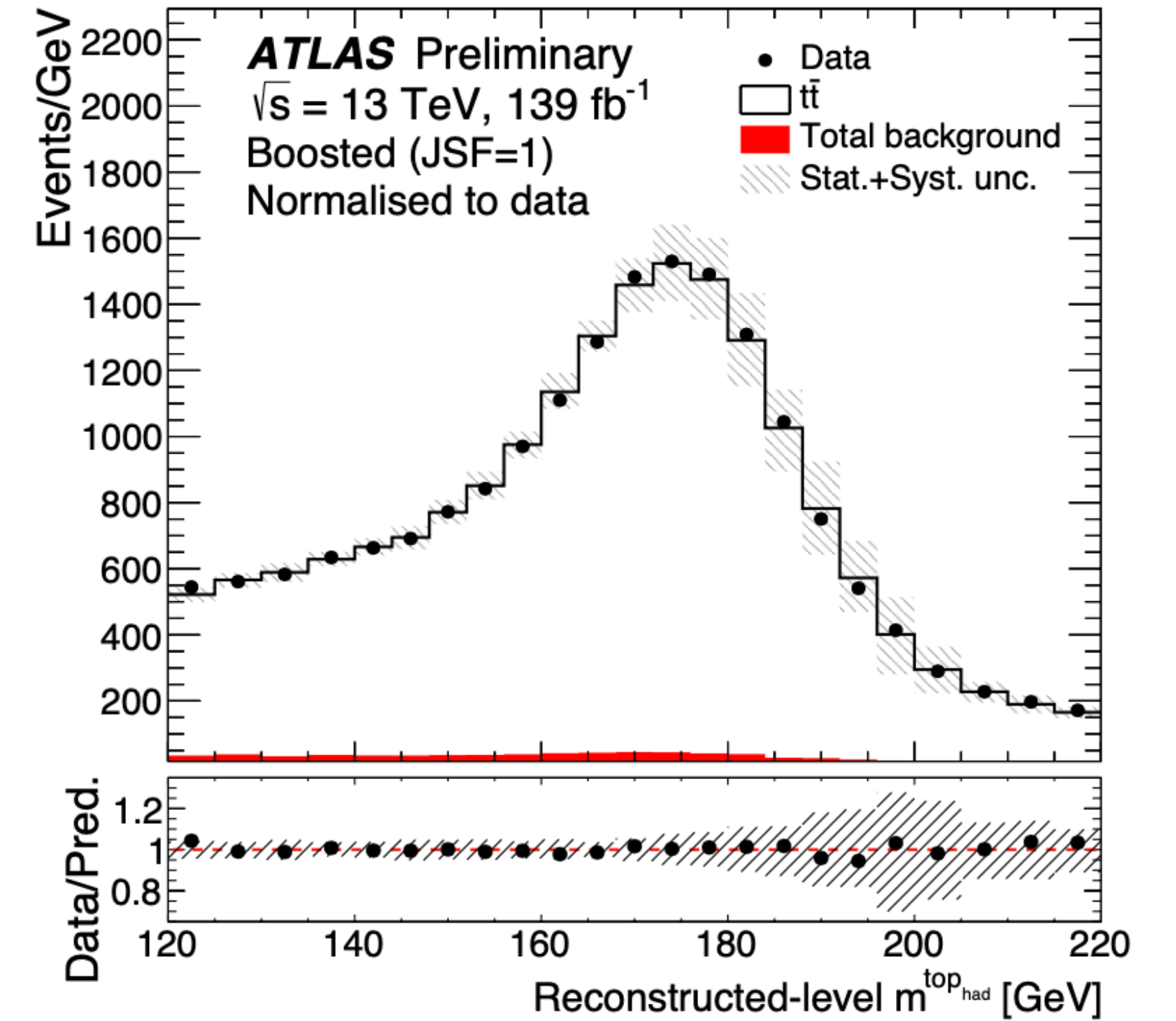
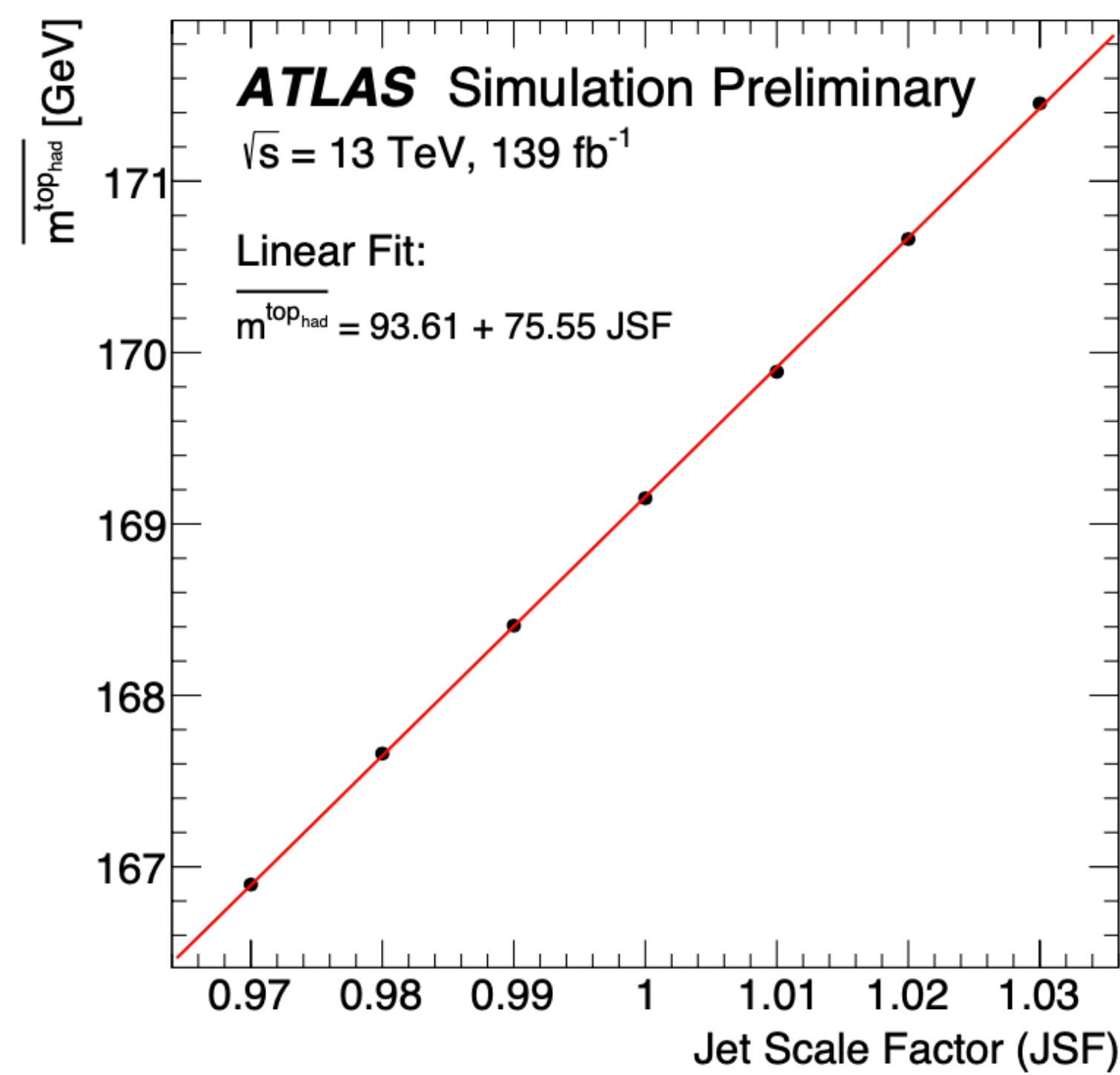
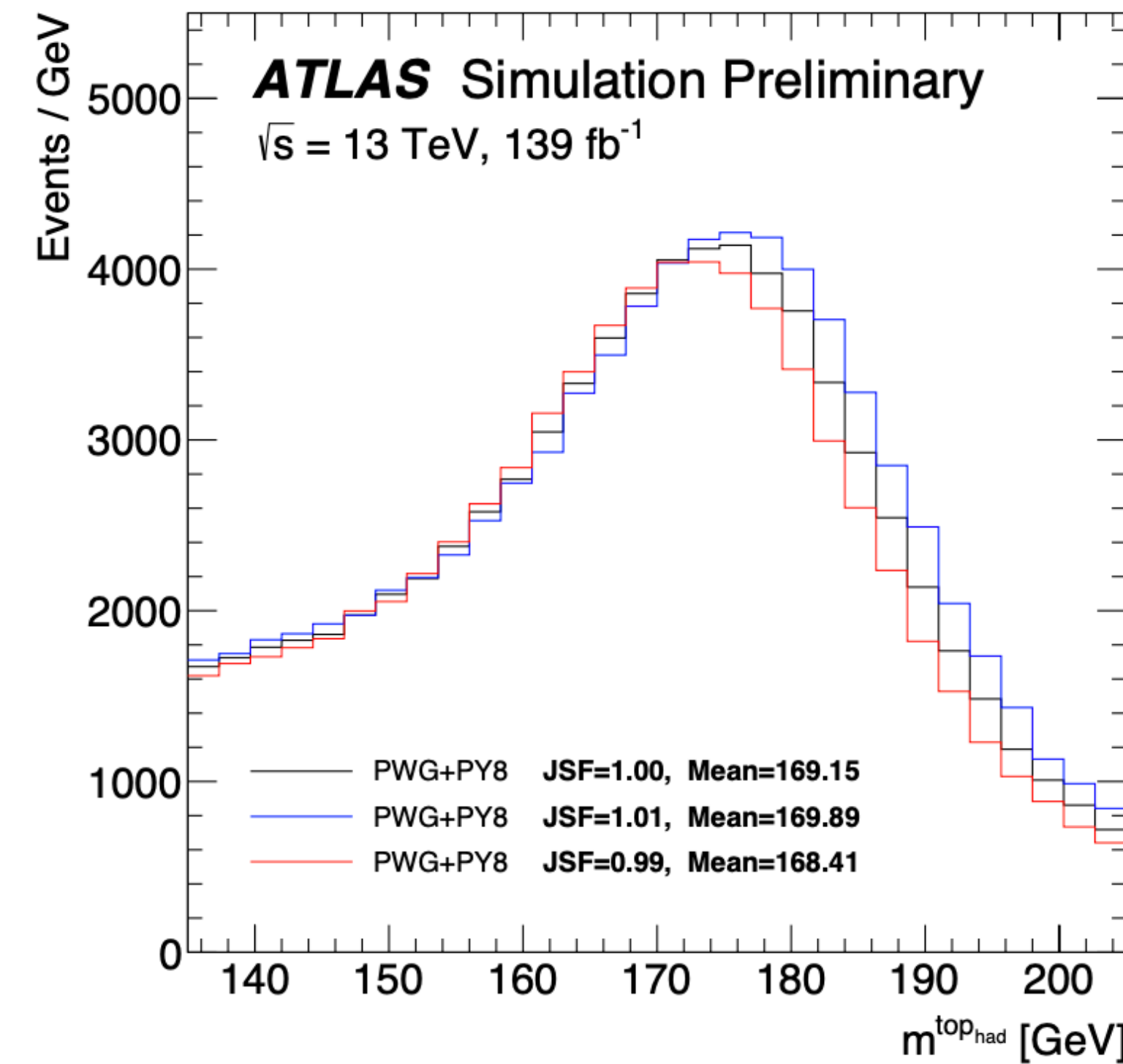
# $t\bar{t}$ production

## Inclusive



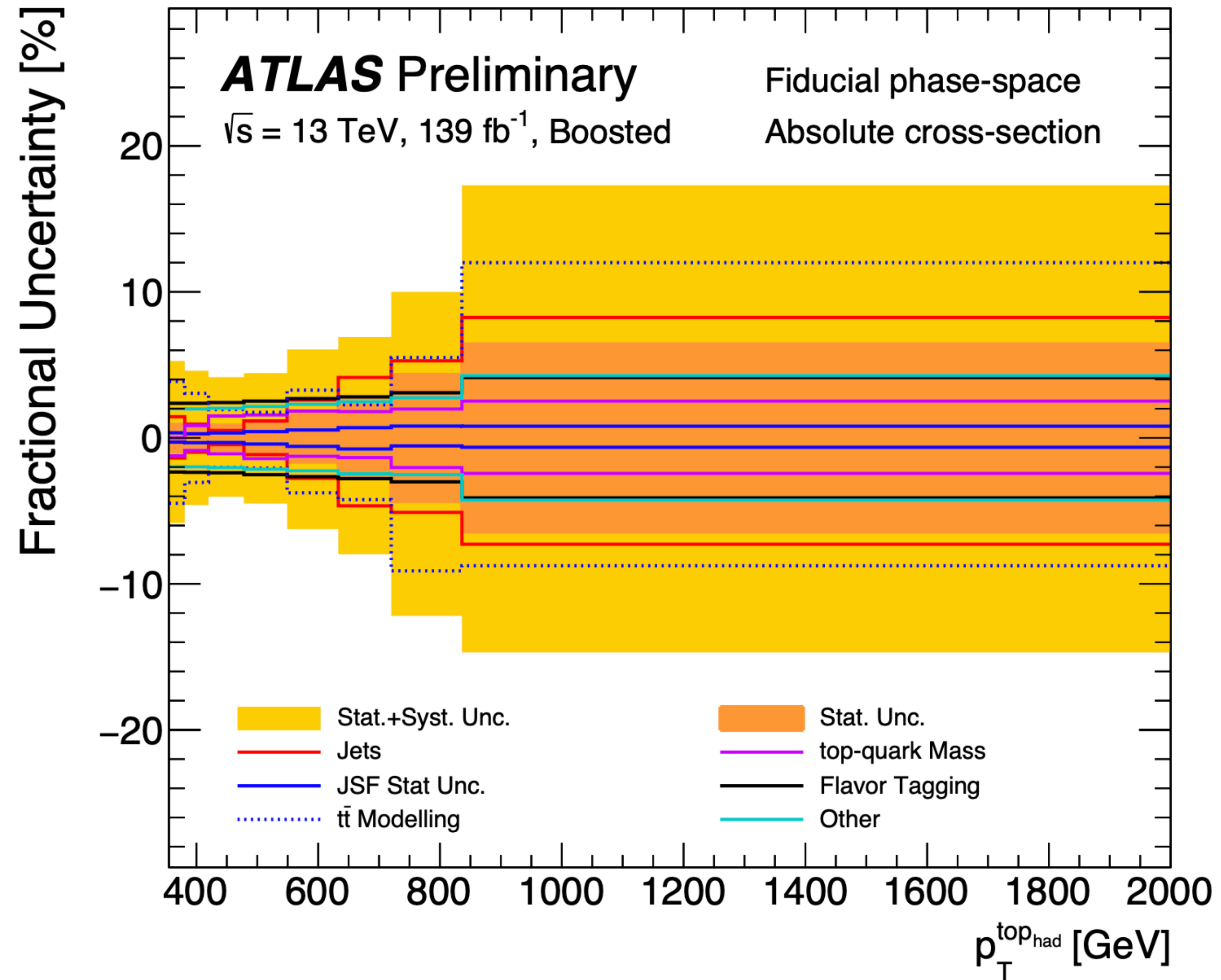
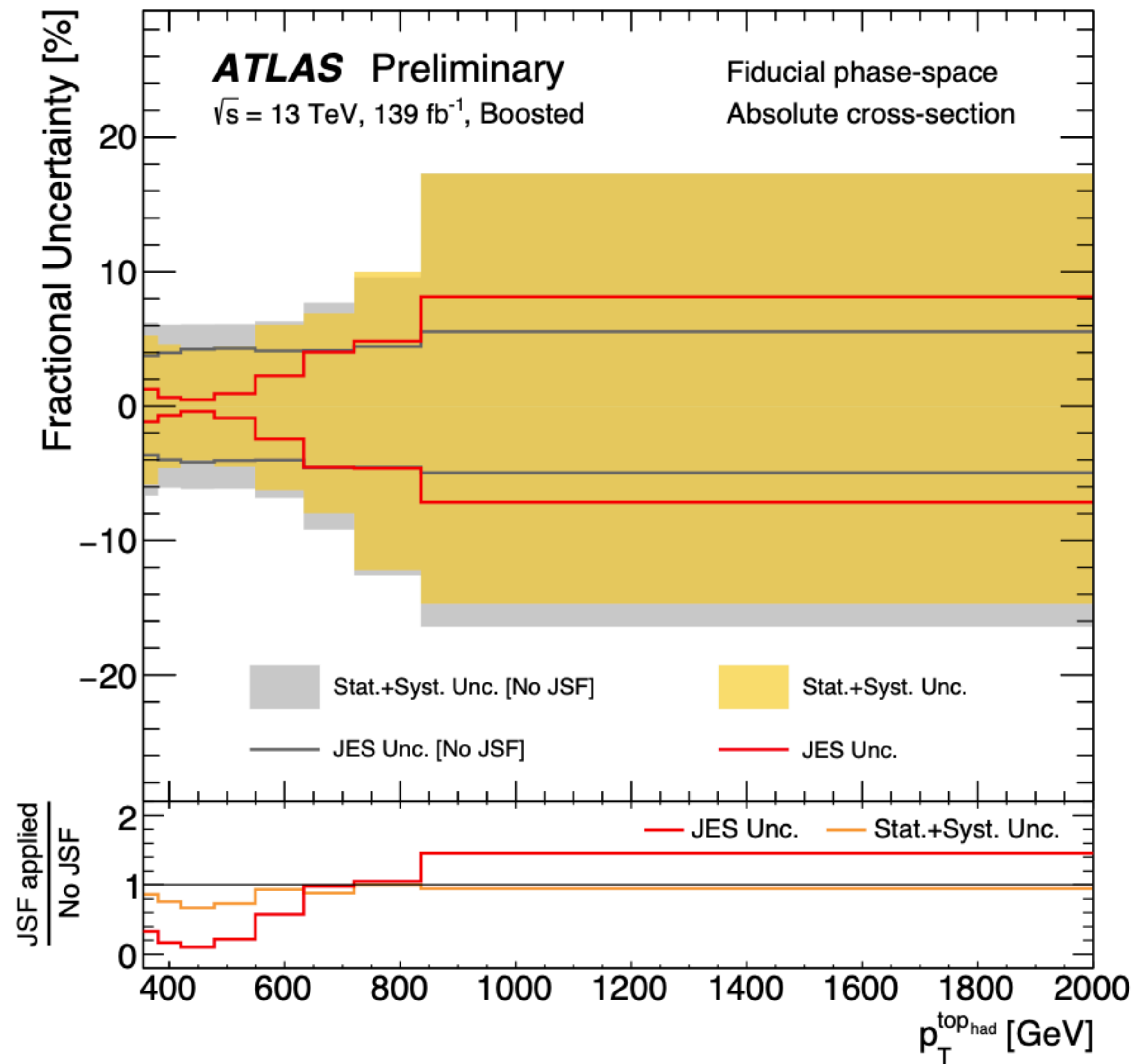


# $t\bar{t}$ Differential: Jet Energy Scale Factors



- Goal: Reduce impact of Jet Energy Scale uncertainty.
- Reconstructed top mass is compared to known top mass (better precision) to derive JSF.

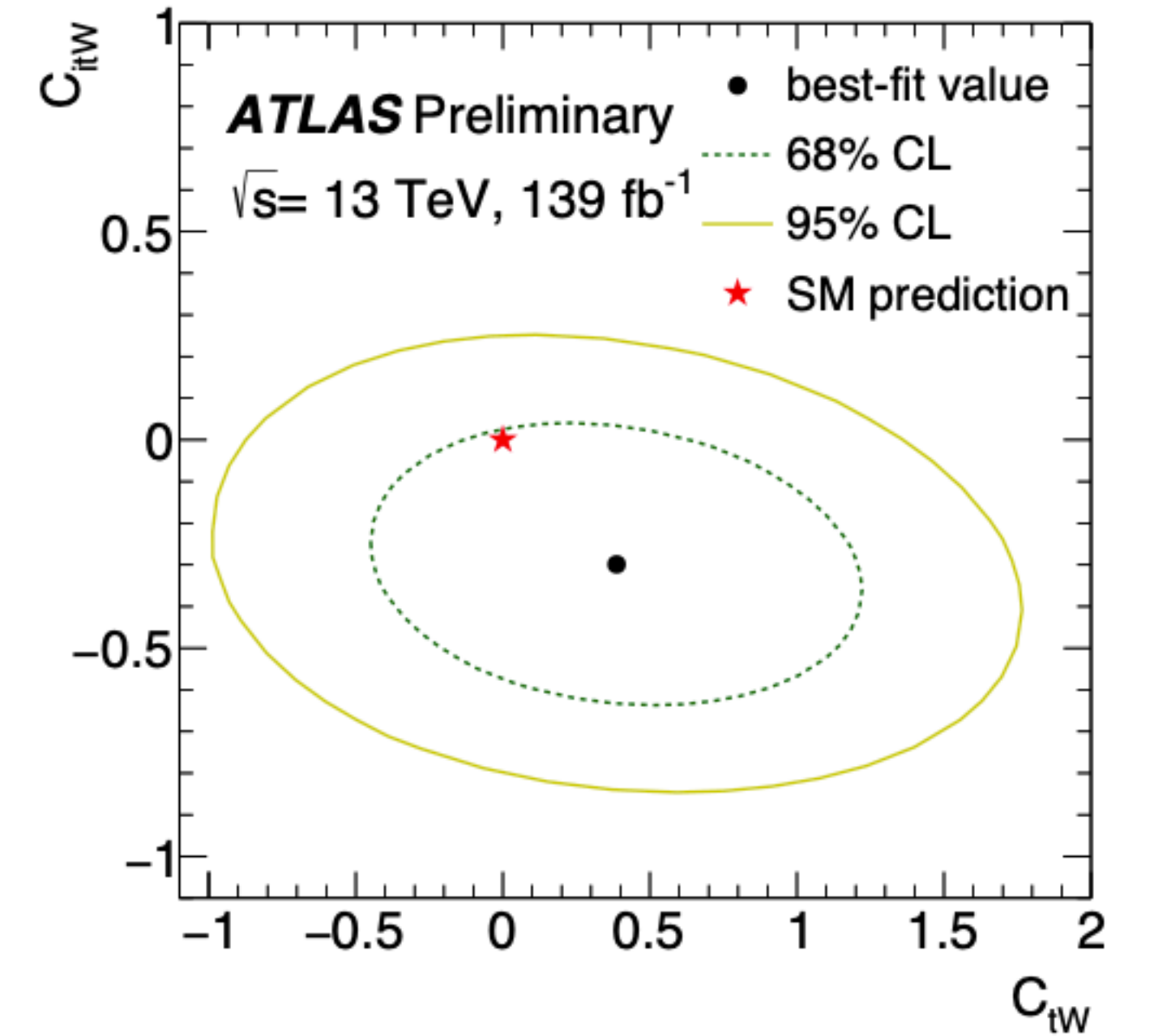
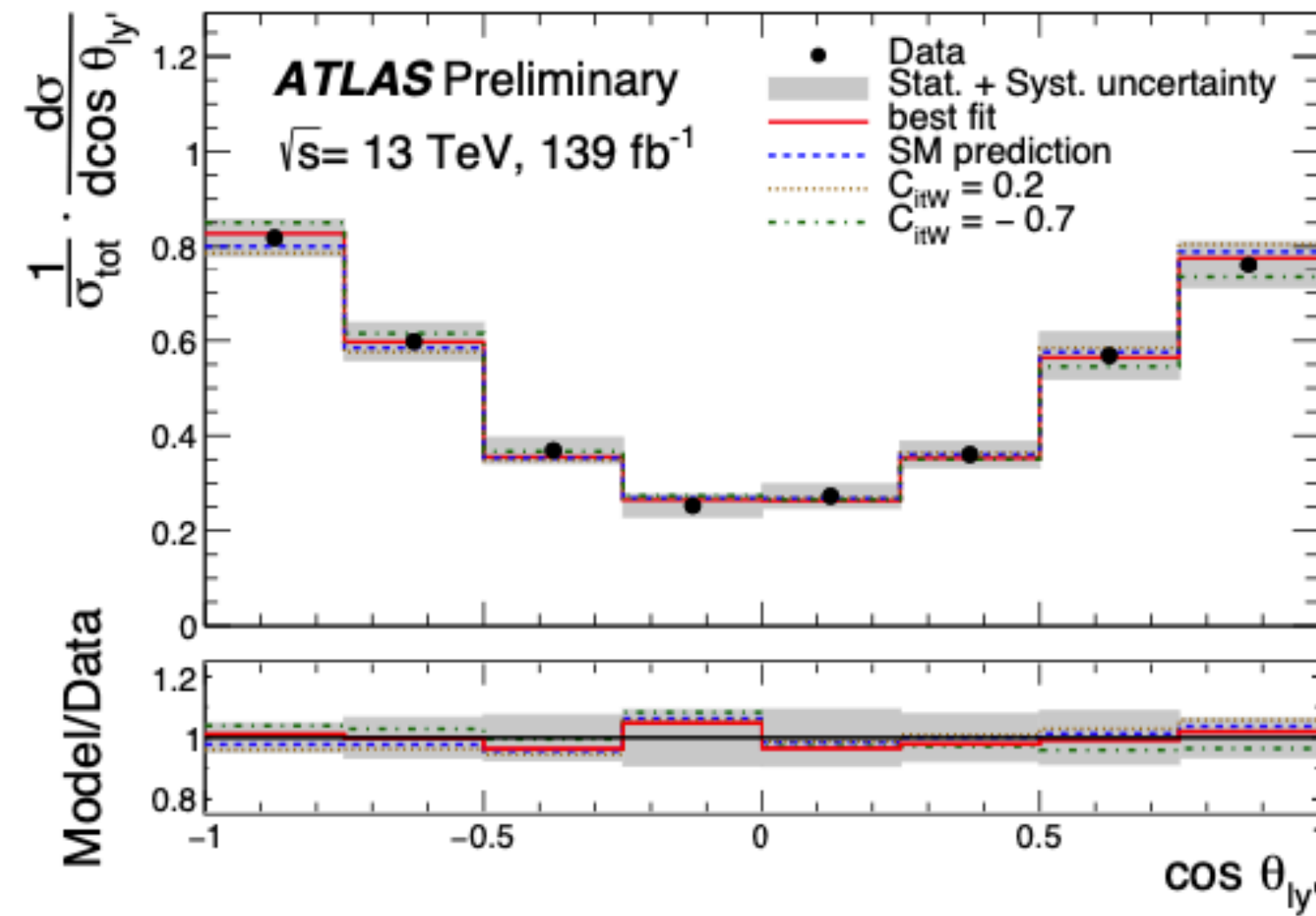
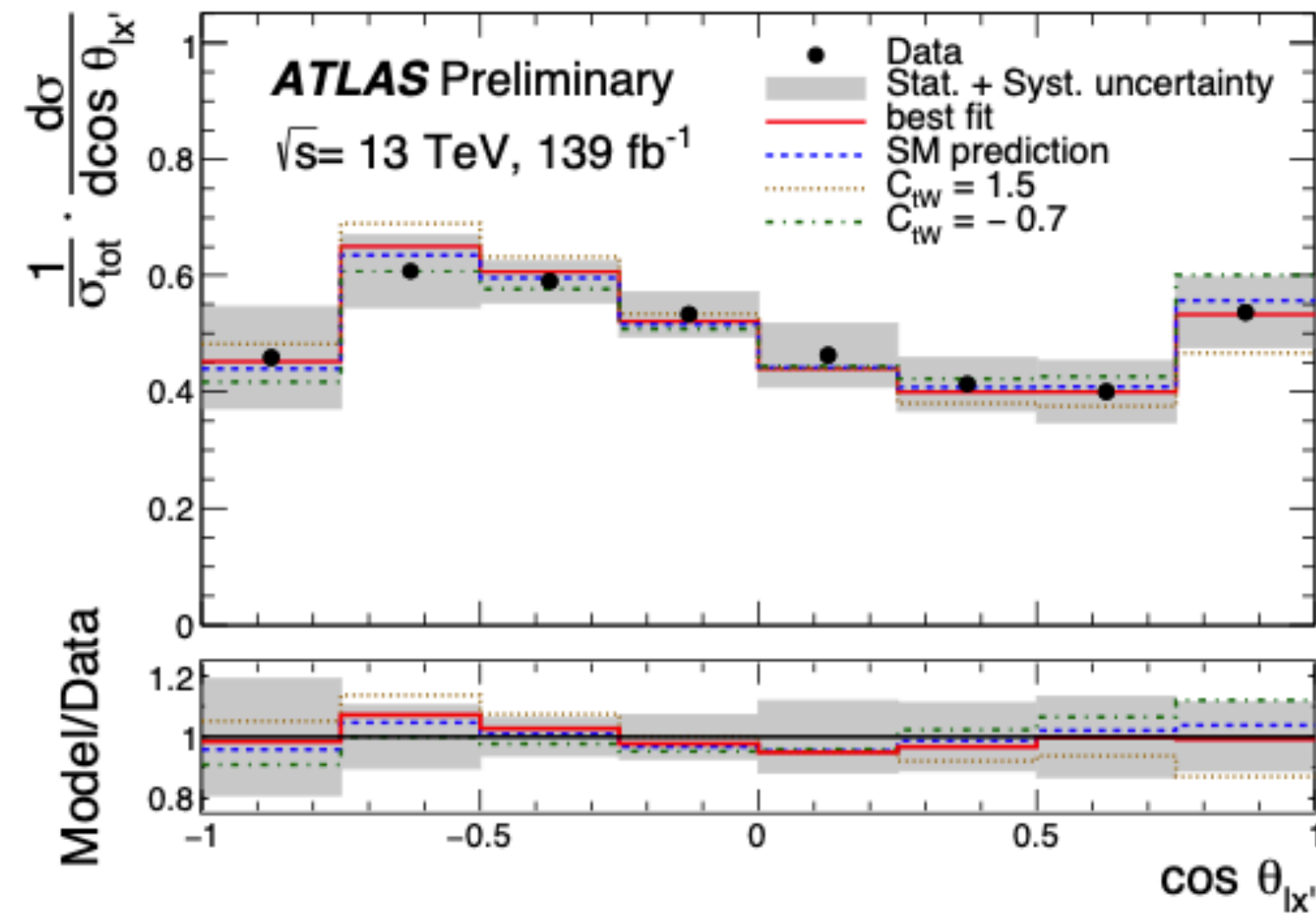
# $t\bar{t}$ Differential: Uncertainties



# Single top: EFT interpretation

- The solid line corresponds to the EFT prediction using the best-fit values for the Wilson coefficients

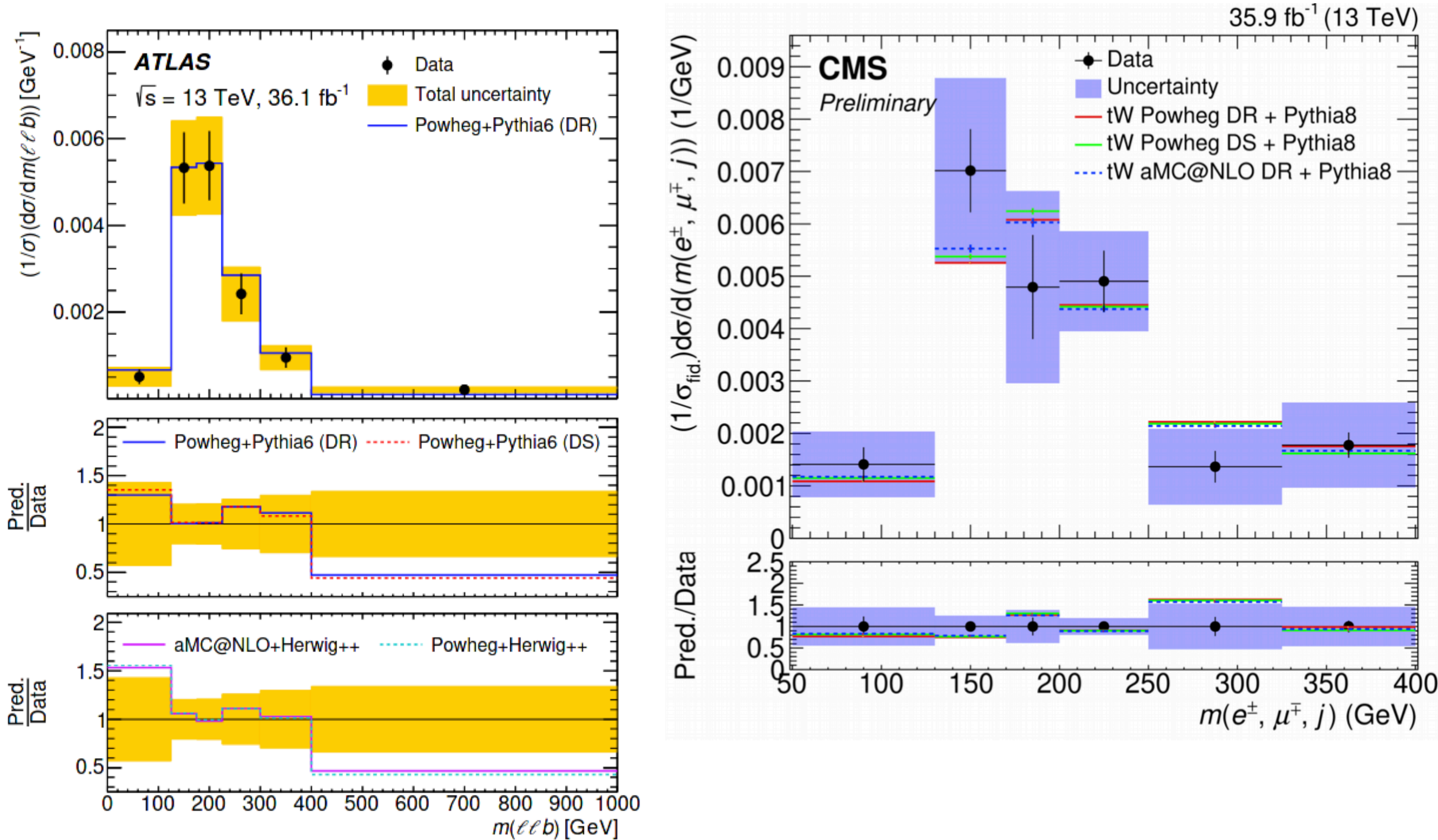
$$C_{tw} = 0.4 \text{ and } C_{itW} = 0.3$$





# Single top production: Differential

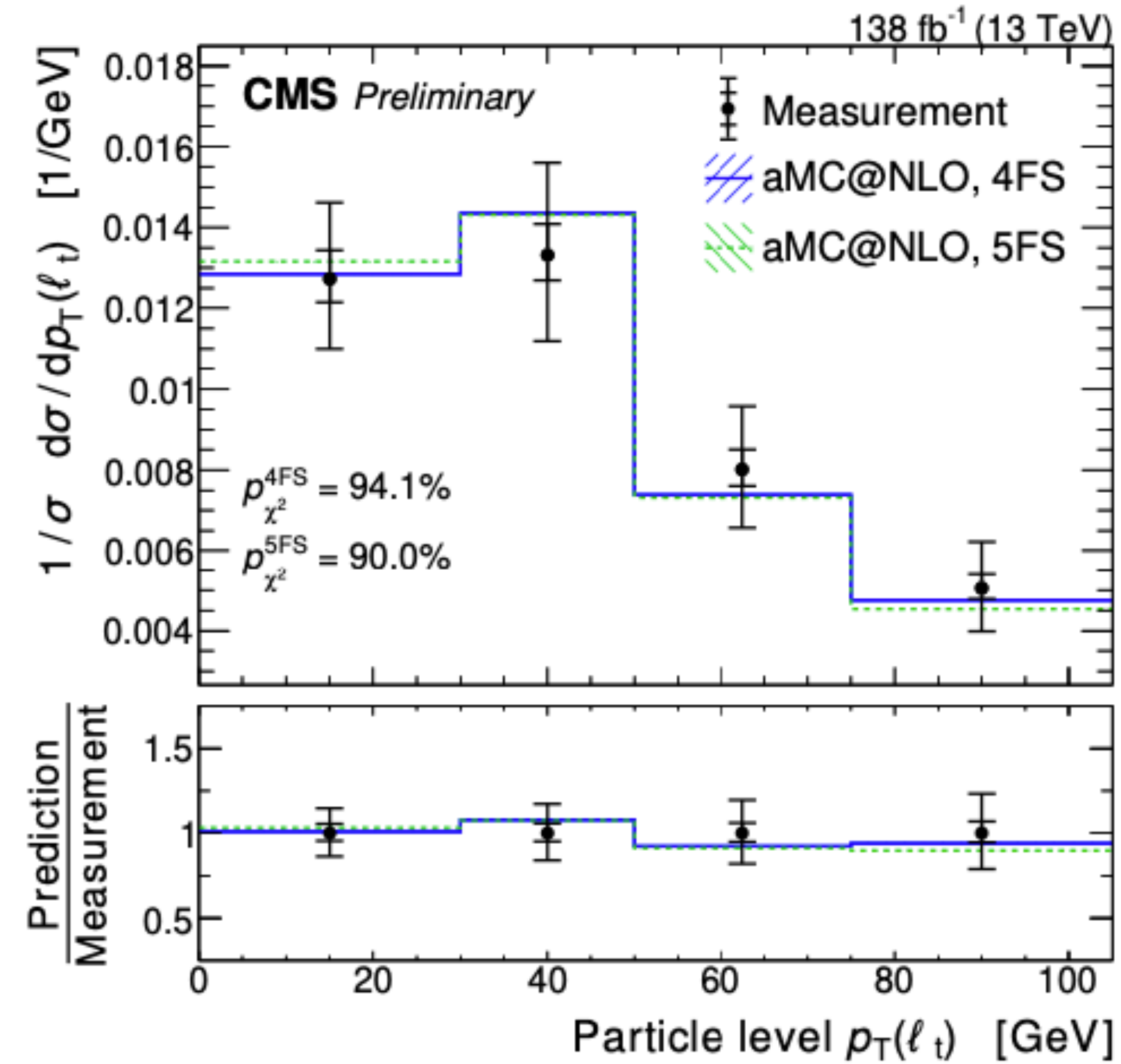
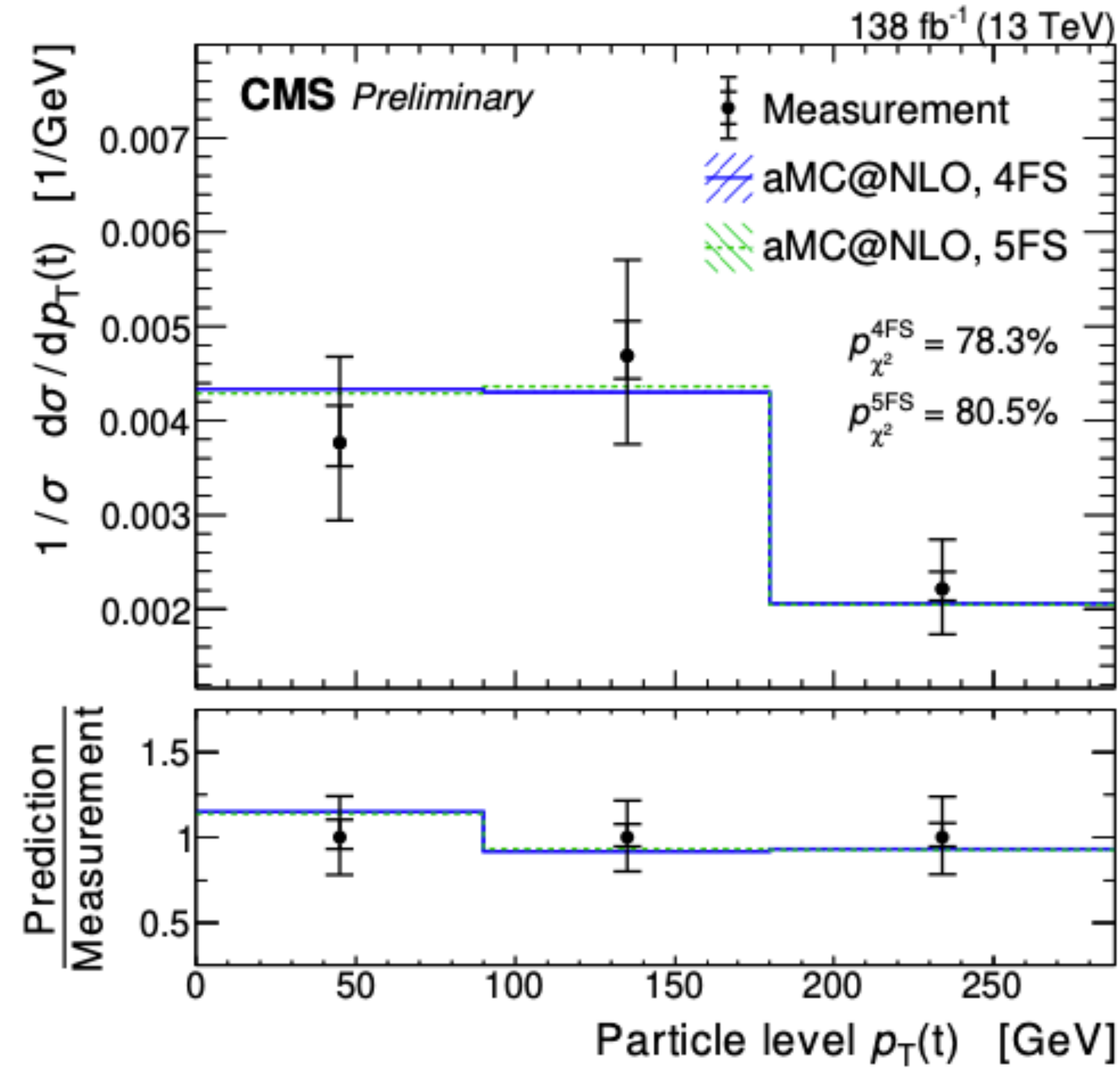
- Showing differential measurement of tW production in dileptonic channel





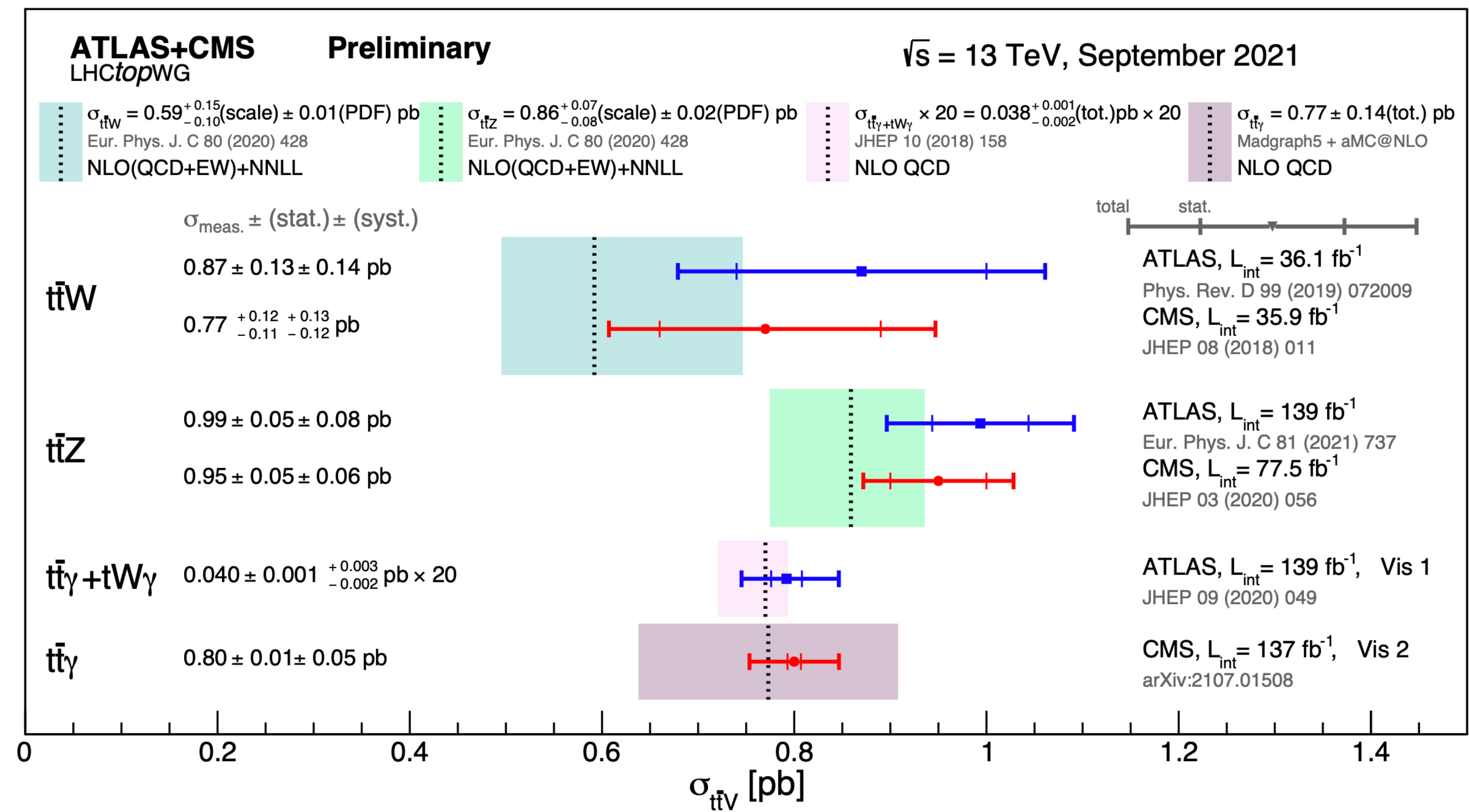
# $tZq$ : Differential and inclusive measurement

CMS-PAS-TOP-20-010



- Absolute normalized differential distributions

# Associated $t\bar{t}X$ production



# Top quark mass

